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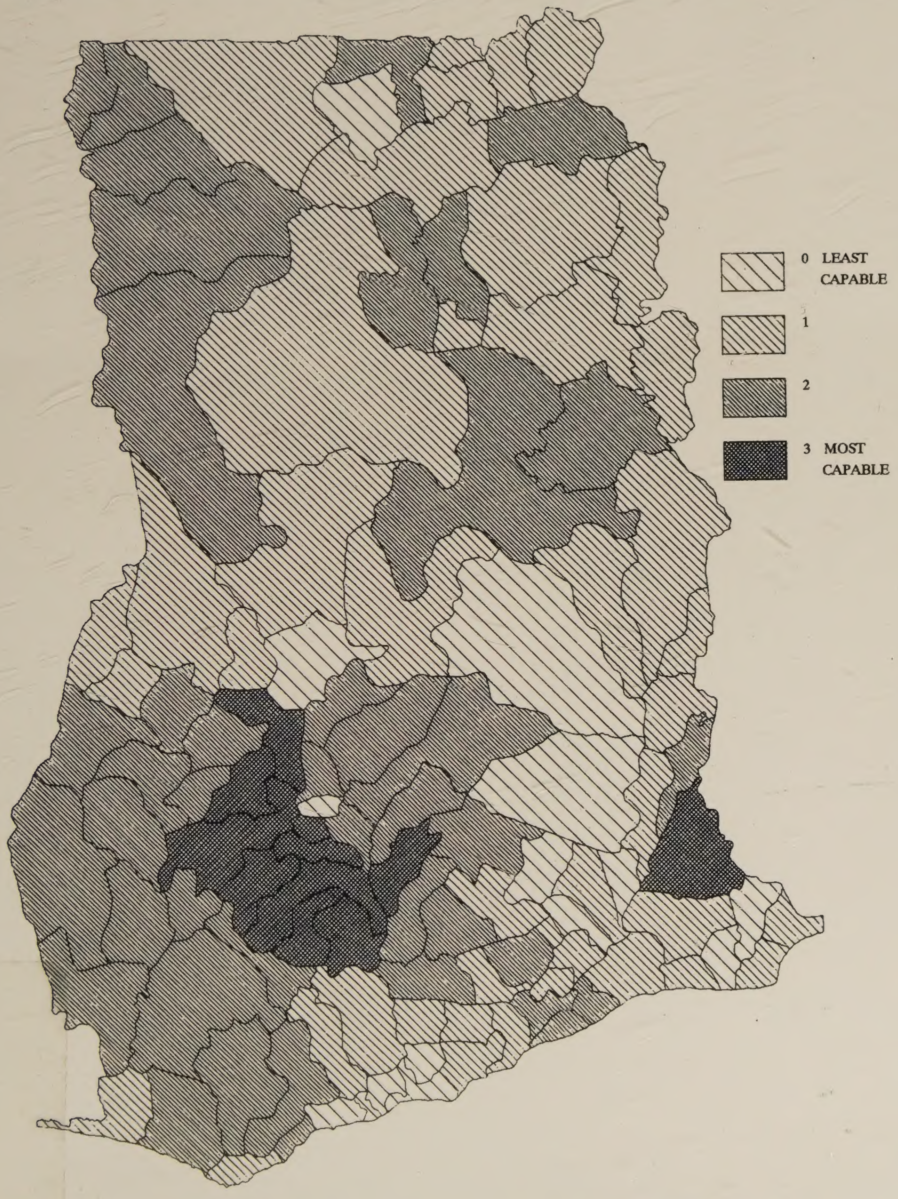
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Geographical information systems and remote sensing in inland fisheries and aquaculture

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PREPARATION OF THIS DOCUMENT

The FAO Inland Water Resources and Aquaculture Service has been active for some years in promoting the use of remote sensing and geographical information systems in fisheries and aquaculture. Promotional activities have been carried out by holding training courses and workshops. However, of necessity, the attendance is limited. A larger audience can be reached only by the distribution of technical material. This document was prepared to meet the need for a reference to remote sensing and geographical information systems that maintains a balance between the technologies and their applications in fisheries and aquaculture. Comments are welcome. Information about related, on-going work can be obtained by writing to:

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Aquaculture Service
FAO, Via delle Terme di Caracalla
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ABSTRACT

The rapidly rising world population is causing both a pressure on land and water space and the need to greatly increase food output. A realistic and practicable way of supplying more food protein is to increase fish production through the extension of aquaculture and inland fisheries. Since production sites for these activities need to satisfy fairly complex location criteria, it is important that suitable areas are identified and preferably designated in advance. The location criteria which control aquaculture and inland fisheries are identified and described. These mainly consist of physical and economic considerations though social factors may be important. It is necessary to obtain data to allow for its mapping. The various alternatives for assembling this data are described.

Two fields of applied science and technology have recently emerged which, when used in combination, can greatly assist in the spatial decision-making process. The fundamentals of the first of these, remote sensing, are described giving particular emphasis to the commercial, high resolution environmental satellites and the sensing devices which they carry. The manner in which the aerial photographic and digital images which are produced can be processed and applied to the search for optimum fish production locations is described, and then indications are given as to where and how remotely sensed data can best be procured. Once the various types of locational data are assembled, the necessary maps on which location decisions are made can be drawn up. This task can be greatly expedited by using the second applied science and technology field, that of "geographical information systems". This emerging methodology relies on the increasing power of the computer to process vast amounts of spatially referenced and encoded data in such a way as to produce any desired maps, tabular or textual output, using a large array of ways to manipulate the data. The required computer hardware and software are reviewed, including examples where appropriate, and we show the considerations which are necessary in setting up a geographical information system for the development and management of aquaculture and inland fisheries. We conclude by giving an divergent selection of relevant case studies.

PREFACE

A number of recurrent and worrying themes increasingly intrude into the comparatively comfortable lives of so many of us - famine, environmental degradation, climatic change, desertification, poverty,inequality, population pressures - and so on. There is a sense in which this study is about all of these things. At the root of many of the problems lies the inability of people to provide for themselves at a most basic level - that is to provide a suitable means of producing sufficient food.

A proliferation in the production of fish may well be part of the solution to this problem. Most readers of this study will be aware that in a few areas of the world, notably in eastern and South-East Asia, intensive and extensive forms of fish rearing have been successful over a very long period of time. Attempts have been made to replicate this success elsewhere but these efforts have had surprisingly little impact, except where aquaculture has been initiated in a highly commercial, intensive form. So, throughout much of the developing world, even where fish production has a great potential to be enhanced,there remains a dominant reliance on imported fish products whose origins are mainly from the decreasing wild-catch fisheries.

One of the barriers both to increasing fisheries output and to enhancing the diffusion processes concerning aquacultural techniques,has been the lack of data on, and methods for, optimizing production locations. A reason for this is that we have generally failed to grasp the significant part which spatial variations, in either physical,economic or social factors, play in the success of a production enterprise. This study is an attempt to show how two rapidly emerging technologies can be utilized to greatly speed up, and make more efficient, location optimizing processes, and how the technologies can allow for a thorough examination of the many spatially variable factors which might affect or control fish production.

The study is written primarily for a variety of personnel in fisheries departments, both in the developing and developed countries.However, since it covers a lot of material relevant to remote sensing(RS) and geographical information systems (GIS), then it could be of value to, amongst others, geographers, agriculturalists, location analysts and to any persons interested in promoting, learning or teaching about these two emerging technologies. We have aimed the study at about undergraduate level, though it could easily be followed by a wider audience since we very deliberately strived to avoid unnecessary jargon and those many acronyms which are so beloved in the worlds of remote sensing and computing! We have also provided further basic reading on particularly important areas covered by the script. Though we are aware that the study will, in some parts, quickly become dated,we are confident that many of the main ideas will enjoy a longer term of relevance, and that a small amount of judicious research could soon make up for the fact that scientific implementation has overtaken us.

After a brief introduction, which sets the scene on both the importance of increasing fisheries production and on securing and optimizing sites for this production, Chapter 2 explains, in varying degrees of detail, the factors which control fish production in both the aquaculture and inland fisheries environments. A large number of mostly physical and economic production functions are identified and discussed. Before any spatial optimization of production can occur, it is necessary to procure relevant data. In Chapter 3 we detail collection techniques for obtaining both primary and secondary data and we suggest that, where this data is lacking or unsuitable, then use might be made of "proxy" data. However, one of the major data sources, remote sensing, is given a complete chapter (No.4) since the data obtained is likely to prove of paramount importance when locations are being considered in much of the developing world, i.e. where traditional spatial data may be non-existent. Additionally, RS data can easily be secured in a favourable, digitized form. We give some background to thetheory and history of RS, we look at different satellites and sensing systems and we briefly cover some of the data processing procedures. We then examine some of the practical and potential uses of RS plus the methods of acquiring and using the necessary imagery. Chapter 5 takes an in-depth look at those traditional mapping sources which have been used in location analysis, looking first at both topographic and thematic maps generally, and then at how thematic maps can be specifically utilized to provide useful information for location optimizing in aquaculture or inland fisheries, or as a source of input data for GISs.In Chapter 6 we examine GISs in some detail, showing first their evolution and development and then going through a step-wise description of how the system's function and the necessary requisites for this functioning in terms of hardware and software. We also show benefits and problems of using GIS and the necessary considerations which must be given before adopting a GIS. We conclude with a variety of case studies which are aimed at showing applications of both RS and GIS to aquaculture and inland fisheries.

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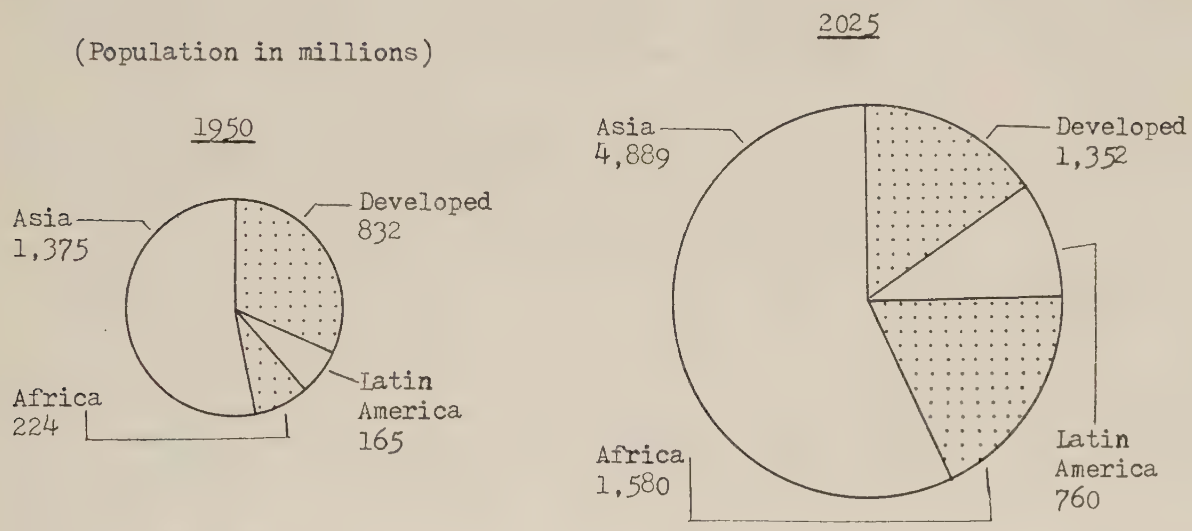
CHAPTER 1 - INTRODUCTION

1.1 Meeting Food Needs

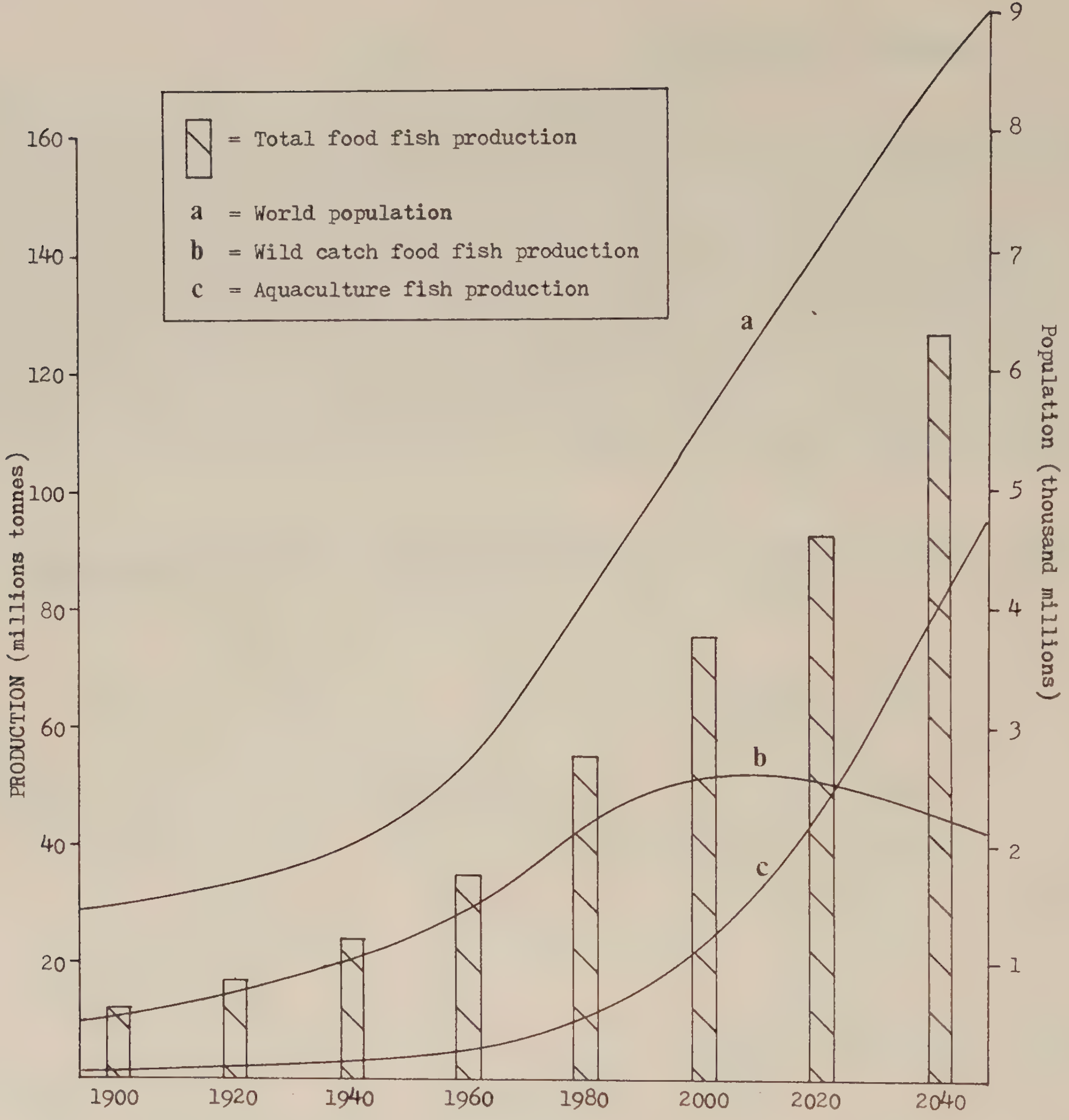
The world's population is currently (1990) increasing at a rate approaching 100 million per annum. Although in the past food production was increasing such that it was able to satisfy rising demands, this has recently ceased to happen and over the last few years food stocks have decreased and/or an increasing number of people are under-nourished, e.g. grain production per person declined in 51 developing countries between 1981 and 1988, with the total number of malnourished increasing from 460 to 512 million (Sadik, 1990). With the world's population likely to quadruple between 1950 and 2025 (Figure 1.1), with it set to more than double before it stabilizes, probably in some 10-12 decades, and with potential agricultural land being already "at a premium", then increasing food yields per hectare must be maintained. Much of this increase must be in the form of protein. At present the production of meat protein in most areas is an energy wasteful strategy, e.g. the protein conversion ratio from feedstuffs to meat is about 20% (Cox and Atkins, 1979).

Figure 1.1 Changes in World Population Size and Distribution



Given this scenario, conventionally produced meat will become an expensive luxury with alternative forms of meat protein being increasingly pursued. Much of this will have to be supplied in the form of fish. Since there is little evidence that wild-catch fish yields can be expanded, production using fish ranching or aquaculture techniques will increase rapidly (FAO, 1989). Figure 1.2 shows that aquaculture production will probably outstrip wild-catch production, at the world scale, early next century. Since intensive forms of aquaculture, utilizing high protein feeds, are also energy wasteful, it is likely that the output of herbivorous species, utilizing low energy inputs in warm waters, will need to rapidly increase. This strategy will be encouraged since, as well as producing greater quantities of food protein in areas where it is increasingly likely to be needed, the activity is able to provide a thriving and diverse employment base, to increase local incomes and to produce a commodity having export earnings potential (FAO, 1987).

Figure 1.2 Trends in World Fisheries - Production and Consumption



1.2 The Varying Nature of "Space" Needs

To achieve the output increases inferred in Figures 1.1 and 1.2, both aquaculture and inland fisheries will require secure access and rights to large areas of terrestrial and aquatic "space". Terrestrial "space" will be mostly in the form of varying sized land parcels sited at the water/land interface - aquatic "space" will be in the form of surface and sub-surface water bodies. The existing availability of both spatial types will show marked variations from country to country or region to region.

The types of, and extent of, "space" required for fish production will vary greatly, not only because of differing local protein requirements, but also because of the complexity and diversity of both the aquaculture and inland fisheries production environments. Table 1.1 gives a simple indication of variations in the production milieu - some of the categories could be in both environments.

TABLE 1.1 The Complexity and Diversity of the Aquaculture and Inland Fisheries Production Environments.

Aquaculture Production Environments

- Tropical v. temperate.
- Intensive v. extensive.
- High v. low capital or inputs.
- Small scale v. large scale.
- Cash v. barter v. subsistence.
- Single species v. multi-species (polyculture).
- Finfish v. crustaceans v. seaweeds.
- Private v. government research and development initiatives.
- Sole farm enterprise v. one of many enterprises.
- Marine v. brackish v. fresh-water.

Inland Fishery Production Environments

- Rivers v. lakes v. reservoirs v. floodplains v. ponds.
- Recreational v. food fisheries.
- Seasonal v. permanent water.
- Shore based v. deep water based - (Inshore v. offshore).
- Central government management v. traditional management.
- Complex v. simple bathymetry.
- Artisanal v. industrial.
- Wild stock v. introduced species.
- Natural replenishment v. periodic stocking.
- Single political unit v. Multi-political unit - (National v. international).

As well as operating in different environments the fish production milieu is interdisciplinary in nature, i.e. requiring data, information, assistance, etc. from the economic, social and physical realms. The production and management systems are also cross-disciplinary in that the producer may have to be an accountant, a biologist, an engineer and a sales-person. Planning and decision-making will necessarily take place in environments ranging from village huts to company boardrooms, and these decisions will emanate from widely varying sociological structures. Additionally the water/land interface used for production is characteristically a diverse and complex ecosystem - one that is likely to be comparatively rare, fragile and environmentally endangered as well as one whose very uniqueness causes it to be highly valued by a large cross-section of the society.

1.3 Pressures on the Available Space

Given that a diverse range of spatial milieux are required for aquaculture or inland fisheries, and that there may be a wide range of activities that threaten the quality of or desire access to this production "space", then inevitably there will be pressures on the water/land interface. These pressures emanate broadly from leisure, urban agricultural, industrial, military, transportation, conservation and personal/domestic interests. The FAO (1989b) has documented examples of these varying interests at the regional level (for N.W. France), whilst at a community level in rural Africa examples of pressure caused by multiple access demands have been extensively documented by Palm (1987). The predominance, and the degree of pressure, from any one of these interests would clearly vary both regionally and temporally.

The consequences of this pressure cannot be underestimated. In more populated areas this is abundantly clear. In such areas a visit to any water/land interface will reveal resource overuse, perhaps physical and environmental degradation and pollution, as well as varying degrees of social conflict. This frequently results in less access and the necessity for regulations. Even in less populated areas, private ownership or land rights, as well as centralized planning decrees, may place severe limitations on the use of sites at the water's edge. Similarly, environmental degradation is not confined to densely populated areas. Lowered water quality and greater variations in water availability downstream result from deforestation in the more remote upstream areas.

1.4 The Importance of Site Selection and Procurement

The importance of matching land requirements with needs for food production generally has long been discussed, e.g. Baker (1921) and Beek (1978), and recently many have cited the importance of securing sites specifically for aquaculture or fish production, e.g. Webber (1972), New (1975), Corrie (1979), McAnuff (1979), Henderson (1985), FAO (1989a), FAO (1989c), Petterrson (1989). Yet little practical work is apparently being done to secure fish production "space". In a recent study (FAO, 1987) of 27 FAO-aided aquacultural projects in developing countries, none of them were concerned with access to water and land, i.e. despite the fact that this had been recognized as a major constraint to rural fish production. This, plus the intense competition for, and pressure on, the limited "space" available for aquaculture and inland fisheries from competitors (see 1.3 above), highlights both the present importance and the urgency of the spatial decision.

From the fish production viewpoint, site selection or location decisions are important initially in the actual securing of production sites, or sites from which to function from. The prospects for securing same will vary greatly depending on existing land/water rights, land use planning controls, availability for purchase or rent, conflicting demands for access, etc. The fish producer will then be concerned to secure sites where environmental parameters can be optimized, preferably in areas where pollution controls or qualitative environmental legislation exists. It is important that sites or locations which allow for economic viability are secured. This could be in areas where optimum sustainable yields can be maintained or in areas where there is at least a reasonable potential for realizing production profits. Sites must also be reserved if future food yields are to be maintained and improved and in order to help the diversification of local employment. Since production requires so many critical physical and economic parameters, and with so many interests competing for the water/land interface "space", the fish producer will need to compete hard for any potential locations.

From the fishery viewpoint, it is important to spatially define and protect the fishing grounds as well as the resources. The latter are mobile. Through migrations for food or reproduction, fished organisms may pass through many environments all of which have other uses.

1.5 Towards Handling the Complexities of the Data

From what has been discussed above concerning the diverse fish production environments, the complexity of the water/land interface, the diverse range of pressures on this interface and the ensuing urgency of the site selection decision, it must be apparent that arriving at a final location decision will only result from an extremely complex decision-making process. Yet the complexities do not end here because, in order to arrive at any spatial decision, data must be available and there must be a suitable methodology for handling the vast array of potentially relevant data.

Until recently, both data availability and data handling facilities have been problematic. There are comparatively few countries or regions which have accumulated much raw data on aquaculture or inland fisheries. Though some production figures usually exist, these (and other figures) are frequently poorly aggregated, incomplete, outdated and vary significantly in their reliability. Other factors for which there is sometimes limited data include the number of production units, size and location of units, number of fishing craft at specific ports and numbers employed, plus the volumes of fish handled in various market sectors. Absolute lack of anything but primitive data on aquaculture and inland fisheries is the rule rather than the exception (Mooneyhan, 1985; Anderson, 1989; Bellemans, 1989). Some of the main spatially related factors for which data is lacking are shown in Table 1.2. The main reasons for this deficiency relate to the lack of appreciation of the importance of accurate, up-to-date statistics to plan for development and to manage resources, the difficulty of obtaining efficient, cost-effective methodologies for collecting and analyzing data and the lack of trained personnel and infrastructure to facilitate information collection and dissemination..

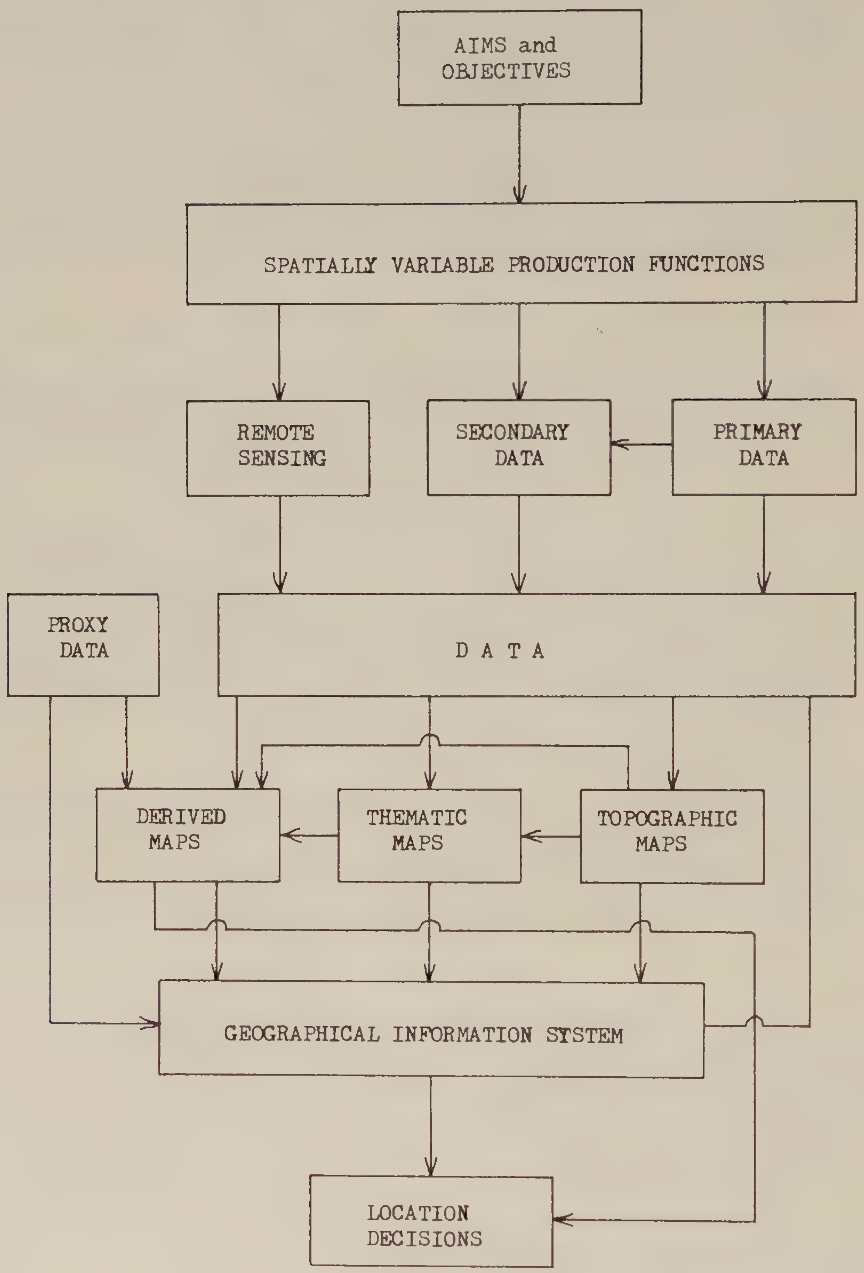
TABLE 1.2 Some Spatially Related Fisheries Production Factors for Which Data is Mostly Lacking - at the level of Individual Water Bodies

a) Biological productivity.
b) Distribution of catch and effort .
c) Social and economic characteristics of fisheries.
d) Transportation pathways and markets.
e) The actual existence of many smaller water bodies.
f) The seasonality of water level - changes and surface area inundated.
g) Detailed bathymetry and limnology of coastal or inland waters.
h) Existing levels of retrograde turbidity or pollution.

Following the perceived need to urgently acquire procurement of "space" at the water/land interface and the need for fish production to occupy carefully selected sites then, in order to expedite this, the proliferation of spatially related (and other relevant) data is now commencing. This proliferation has only been able to occur recently, since we are now in a position to store and handle vast amounts of data through use of the computer - a technology whose very existence is likely to reinforce its own utility through the exponential proliferation of data! Spatial, or location related, decisions are now being handled by that branch of computing known as "Geographic(al) Information Systems" (GIS).

Figure 1.3 shows schematically how the spatial decision-making process can be accomplished in order to best secure optimum sites for fishery production. It represents a structured flow whereby the first three "levels" are all basically processes whereby the data needed for inputs into the location decision-making process are obtained. In the middle is the data, both directly relevant and "proxy", followed by a further three "levels" which represent the processes that permit location decisions to be made. Clearly the diagram is simplified, e.g. there would be sub-categories of inputs, processes and outputs at all "levels". We shall structure this study in the same sequence as this, though there will not be a specific "data" chapter and the "location decisions" will be represented by a number of case studies.

Figure 1.3 Schematic Diagram Showing Stages in Spatial Decision Making


AIMS and OBJECTIVES
SPATIALLY VARIABLE PRODUCTION FUNCTIONS
REMOTE SENSING
SECONDARY DATA
PRIMARY DATA
PROXY DATA
D A T A
DERIVED MAPS
THEMATIC MAPS
TOPOGRAPHIC MAPS
GEOGRAPHICAL INFORMATION SYSTEM
LOCATION DECISIONS

CHAPTER 2 - SPATIALLY VARIABLE PRODUCTION FUNCTIONS CONTROLLING AQUACULTURE AND INLAND FISHERIES

2.1 Production Functions

The pursuance of any human activity will be controlled by a varying number of factors. Those factors controlling economic activities have been called "production functions", i.e. since what is produced is a function of various combinations of the controlling factors. The necessary combination of production functions will vary both between and within enterprises in an almost unlimited way; usually more complex activities will involve more production functions. Production functions are most frequently economic factors though they may also be physical factors and to a lesser extent social factors. Most economic production functions will be synonymous with "fixed" or "capital" costs in that they involve "once only" consideration, usually when the activity is being initiated. Other functions will be variable, i.e. synonymous with "variable operating" costs and considerations.

All production functions will show spatial variability. Specific functions will vary greatly within a given area - others hardly at all. A particular production function may vary greatly within one country (or region) but hardly at all in another. Production functions, especially economic ones, will also show temporal variations. These temporal variations are mostly responses to cost fluctuations which themselves respond either to inflationary cycles or to more immediate supply/demand situations. It is increasingly possible to manipulate production functions. Obviously economic functions undergo almost continuous fluctuations as costs and markets change, but increasingly physical functions can be manipulated, e.g. by building a pond, by fertilizing soils or by aerating water. Social manipulations occur by such factors as altering food preferences, as exemplified by the increasing popularity of take-away foods, or by the marketing of more value added prepared foods.

The rationale for most economic (commercial or business) activities is profit maximization or cost reduction. Enterprises will seek to manipulate production functions in such a way as to best secure the maximum return for the minimum outlay of time, capital or effort. For the rest of this study we must take profit maximization as our production rationale since failure to aim for this objective will mean that there is no point in seeking suitable locations for aquaculture or inland fisheries, i.e. with enough capital it is possible, through the manipulation of production functions, to produce almost anything anywhere.

From the spatial perspective there are two ways in which the optimizing of production functions can be viewed. Firstly, we can take the view that most farmers must take, i.e. "Given this piece of land which I own (or rent), what is the best way of using it?" The farmer must then consider how he can best organize and manage his choice of activities (usually crops or livestock) so as to achieve this usual goal of profit maximization. The second viewpoint, which is often used by industrialists and is increasingly being recognized as being of importance to all economic activities, is - "To produce commodity x, where best should production take place?" This question has long formed the core of spatial optimizing theory (e.g. Weber, 1909; Hoover, 1948; Loesch, 1954; Isard, 1956), and it is the fundamental question which forms the core of this present study.

We should not underestimate the importance of getting the spatial decision right. For many fish farmers this may be a once in a lifetime decision for, unlike normal farming practices where crop or livestock mixes can be regularly manipulated in order to achieve optimal combinations, where expensive fixed assets are required the location decision, based on optimizing production functions, is seldom repeatable. Clearly, the study of production functions *per se*, their spatial variability and the mixes of same is absolutely vital if correct spatial decisions are to be made.

Since the reader may be familiar with much of the factual information on production functions, the rest of this chapter will attempt to draw attention to their spatial variability aspects.

2.2 The Production Function Mix Controlling Aquaculture or Inland Fisheries

It has been shown (in section 1.2) that both aquaculture and inland fisheries are complex production activities. The range of controlling production functions will therefore be large and will vary greatly between and within regions, with different production systems, with different species being produced, etc. Table 2.1 shows typical production functions controlling freshwater aquaculture (FAO, 1988 with some additions), and Table 2.2 shows those functions controlling the mariculture of oysters (Cordell and Nolte, 1988b); further, very detailed lists can be obtained from Coche (1985) or Duncan (1985). Most of the functions shown in Table 2.1 are fixed (once only) considerations - there would also be a range of more detailed economic factors to consider.

Table 2.1 Typical Production Functions Controlling Aquaculture

a) Land availability
b) Land ownership
c) Topography
d) Climate
e) Water availability
f) Water quality and temperature
g) Water rights
h) Potential for competitive water use
i) Soil - chemistry, permeability, compaction, texture
j) Predators
k) Adjacent land uses
l) Proximity to supporting infrastructure
m) Access - roads, bridges
n) Potential and severity of major climatic disturbances
o) Local political, social and economic factors
p) Leases and permits (required and status of)
q) Environmental constraints and impacts
r) Susceptibility to poaching, i.e. security

The production functions themselves will be of varying importance. Though it is possible to identify universally important functions, it is impossible to state which functions are of which relative importance since this will vary not only objectively, i.e. between types of production units, size of units, types of system, etc., but also subjectively in the sense that some fish farmers would be in a better position than others to overcome perceived difficulties or problems.

Consideration of those spatially variable production functions which cause variations in the efficiency of fish production from area to area demands that a number of general factors are reviewed. Firstly, it will be apparent that it is not always possible to clearly differentiate between one function and another. For example - should water quality and water temperature be considered as two separate functions, when the former may be partly a function of the latter. Similarly, many climatic variables will be related to water temperatures.

Table 2.2 Production Functions Controlling the Mariculture of Oysters

a) Proximity of water and shoreline.
b) Water depth at low tide.
c) Protection from excessive wave action.
d) Existence of stream mouths.
e) Proximity to potential or actual landslide areas.
f) Electric power availability.
g) Road access.
h) Boat access.
i) Communications.
j) Proximity to markets.
k) Proximity to labour.
l) Upland use.
m) Water use.
n) Water temperature - summer and winter.
o) Salinity - summer and winter.
p) Dissolved oxygen.
q) Currents.
r) Circulation.
s) Protection.
t) Predators.
u) Pollution.
v) Freshwater.
w) Phytoplankton concentration.

Secondly, it would be possible to subdivide some production functions into narrower categories, e.g. markets for fish could be subdivided by type - perhaps "Wholesale" and "Retail". These in turn could be subdivided into "Processors", "Smokers", "Freezers", "Supermarkets", etc. Clearly, any final choice of relevant production functions must depend on the exact circumstances of the study though anyone who is intrinsically involved in activities such as aquaculture or inland fisheries will recognize fairly definite functional sub-categories.

Thirdly, if we examine spatial variations in production functions at very different spatial scales, then differing functions may dominate. For instance, at a small scale (say an area 10km x 10km) considerations of relief, bathymetry, shelter and soils might be very pertinent site specific factors, but at this same scale considerations of evaporation rates, distances to main markets or access to extension services would be of only minor relevance. Clearly, at larger scales distance functions would be of far greater significance as would considerations of volume supplies of goods, the marginal utility of land, etc.

Fourthly, it may often be the case that the spatial disposition of any individual production function will alter, sometimes significantly, at an internal or national boundary. This would especially apply to economic functions. Thus Lindquist and Mikkola (1989) have shown how spatial variations in production functions between the four contiguous riparian countries around Lake Tanganyika, lead to completely different production pressures on the one lake.

There has been little research aimed at identifying the extent of economic penalties liable from poor locational choice, though it has recently been shown (Muir and Kapetsky, 1988) that financial penalties do accrue in locations where production function mixes are sub-optimal. The degree of this penalty would vary from enterprise to enterprise and therefore it is difficult to apply generalized models of production function mixes to existing locations.

Though there are many production functions which control aquaculture and inland fisheries in varying degrees, it will only be possible to examine some major functions in detail, i.e. chosen to illustrate the breadth of spatial considerations necessary, and some minor functions very briefly. For each major function we will endeavour to review:

i) The ways in which the function might control fish production.
ii) The causes of production function variability.
iii) The degree of possible manipulation of the function.
iv) The degree of variability of the function at the macro and/or micro-scales.
v) Spatially related considerations that the intending entrepreneur, fishery planner or fishery manager should be concerned with.

2.3 The More Important Production Functions Controlling Aquaculture and Inland Fisheries

In this section it is intended that sufficient information is given such that any prospective fish producer would be aware of the essential elements or pitfalls in seeking optimum locations. It would then be in the interests of all intending fish producers to seek out more precise production function parameters before investing in any potential or intended enterprise.

2.3.1 Water Quality

Since each aquatic species will have its own optimum and extreme range of water qualitative parameters, it is impractical to do other than review the application of some of the more obvious qualitative factors, i.e. essentially those which can be readily monitored and measured. Table 2.3 briefly states the manner in which the water qualitative parameters determine the effect on aquatic growth and suggests how the parameter is influenced. Further details can be obtained from Alabaster and Lloyd (1980), Pickering (1981) or Payne (1986). Many other qualitative parameters could be defined but most would apply only to specific locations, e.g. pollutant sources from farm wastes and chemical applications; from mining seepages or heavy metal contamination; from industrial effluents or from urban areas (especially sewage outfalls).

The reasons why water quality varies over space can be conveniently divided into a) natural causes and b) human influences. Natural causes relate primarily to three major factors: precipitation, rock weathering and evaporation (Payne, 1986). Water of higher temperature is more prone to qualitative degrading, e.g. reduced oxygen levels, excessive nutrient accumulations, etc., and heavy rainfall may significantly increase turbidity through excessive run-off. Geology affects water quality by determining the rate of rock disintegration, and the rock type through (or over) which water may flow. In so doing it can accumulate dissolved minerals, such as calcium or sodium, or more concentrated minerals seeping from specific natural sources. Total ionic concentrations will generally progressively get higher further downstream and be higher during the dry season when the influence of ground water is greater. More turbulent patterns of water flow will enhance the oxygen content. Human influence on water quality is largely through unregulated activities which allow leakages or discharges from a diverse range of human activities, i.e. related to industry, mining, agriculture and urban sprawl.

Generally there are few chances of controlling or manipulating the larger scale negative water qualitative factors. Though some methods are practicable , e.g. clearing excessive water vegetation to adjust oxygen levels or by adding lime to increase alkalinity levels, in general the cost of continuously carrying out these procedures is prohibitive. It is only some highly intensive culture practices which can afford to moderate water quality, e.g. by water aeration to increase oxygen content when water temperatures are excessive. At the smaller scale effective pollution controls are certainly feasible, though this may depend upon the goodwill and financial situation of a third party. Larger scale pollution is certainly one of the major limiting factors to fishery expansion: this problem would usually need to be tackled collectively, probably via the use of statutory measures.

Table 2.3 Some Major Water Qualitative Parameters Controlling the Fishery Environment

Water Qualitative Parameter	Controlling Function on Aquatic Organisms	Control of Parameter
Oxygen	Regulates metabolic functions, e.g. respiration and food utilization. Enhances stressful effects of other toxicants. Increases probability of disease.	Increased water temps.., reduces dissolved oxygen capacity. Plant abundance reduces oxygen capacity. Faster water change rate increases capacity.
pH	Excess acidity or alkalinity retards growth, i.e. preferred range is 6.5 to 8.0. Acclimation possible, but growth rates slowed. Helps determine nutrient availability.	Increased pH with high rainfall, poorly buffered water or run-off from strip mining, excessive soil erosion and some agricultural activities. Lower pH with igneous rocks, marsh, heath or peat areas.
Ammonia	Un-ionised form is acutely toxic to the nervous system and brain. Causes gill damage. Excess retards growth. Can accelerate eutrophication.	Levels of faeces build-up needs monitoring in intensive systems. Regulation of upstream sewage effluents or silage discharges.
Carbon dioxide	Reduction in oxygen affinity. Increase in incidence of nephrocalcinosis.	Reducing spring or bore hole water supplies. Regulation of aeration patterns in intensive culture.
Suspended sediments	Obscures feeds. Accelerates incidence of several diseases. Reduces light available for plankton growth.	Increased by vegetation clearance, heavy rain, excessive run-off.
Phosphates and Nitrates	Determines level of nutrients for phytoplankton growth. Speeds up eutrophication.	Regulation of inorganic fertilizer residues.

There is little comprehensive information on which to assess the extent to which poor water quality limits fish production on a world scale. Certainly Palm (1989) notes that it is uncommon for African water bodies to have fish growth inhibited by poor water quality. However, in other more developed parts of the world, the overall situation would certainly be deteriorating, largely due to rapid urban and industrial developments, to major forest clearance and to the increased use of agricultural chemicals. Indeed, in some of the more advanced developing countries the situation is already quite alarming, e.g. Menasveta (1987) has shown that, although the situation is now improving, mariculture output in Thailand declined from 148 369 tons in 1977 to 23 902 tons in 1982 due almost entirely to coastal pollution. Additionally, Lindquist and Mikkola (1989) have shown how even in a very large body of water such as Lake Tanganyika, the growth of pollution is evident. In many developed countries massive water clean-up efforts have been implemented but even here headway has not always been achieved. At the localized scale, water quality can be extremely variable, especially in the developed world. Table 2.4 summarizes those spatial considerations concerning water that should be of concern.

Table 2.4 Summary of Spatial Considerations Relating to Water Quality

a)	Water qualitative parameters for the species being reared.
b)	Potential pollution sources upstream from any chosen site.
c)	Any temporal variations in individual pollutants.
d)	Any plans for local expansion of agriculture, industry, etc.
e)	Current strategies for controlling potential local pollutants.
f)	Whether planned stocking densities or quantities will be detrimental to present water quality.
g)	The control of water flow in case of water qualitative emergencies.
h)	The extent of qualitative data available for any proposed location.
i)	Local or national legal constraints on water quality.

2.3.2 Water Temperature

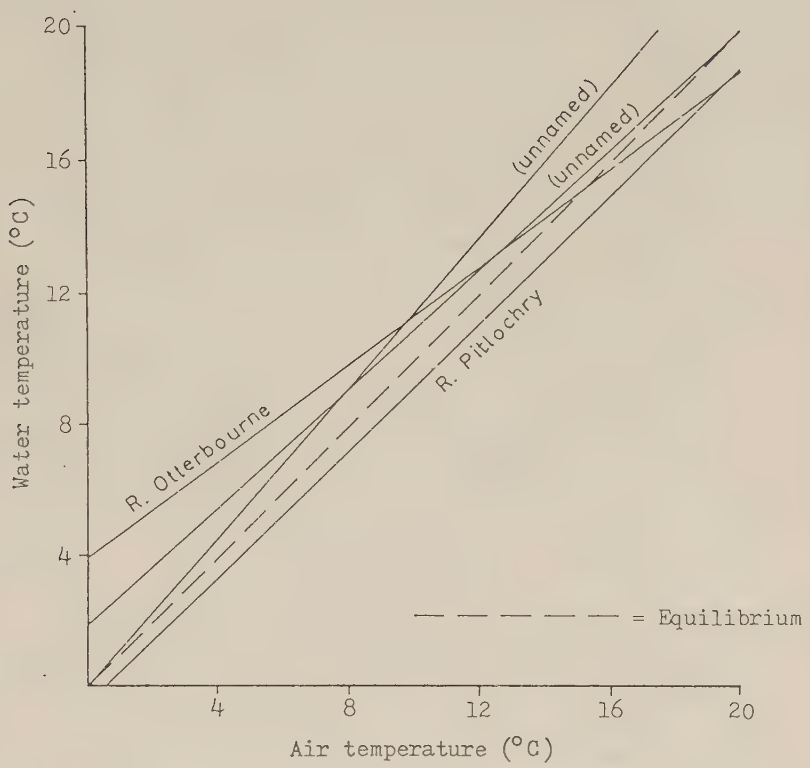
Food intake, genetic constitution and water temperatures are the most important determinants of fish growth rates (e.g. Cooper, 1961). Since it is within the power of the fish farmer to control food intake and to select for genetic advantages, it will be apparent that actual water temperature will be a prime consideration in the selection of locations for fish culture, e.g. several authors (Allen, 1941; Weatherly and Lake, 1967; Bulleid, 1974) have shown that the time taken for trout to achieve marketable size can be greatly reduced if the temperature could be maintained within the optimum range.

Although all species have a preferred water temperature range, an optimum temperature range for maximum growth and a range of maximum and minimum tolerance, most can be acclimated to slightly different temperature regimes. Many species are well adjusted to seasonal fluctuations in the range e.g. most salmonids, whereas others, mainly tropical species, prefer homothermic conditions. In the optimal temperature range, metabolic rates will be high and thus there is the greatest likelihood of the fish eating more food than is necessary for maintenance alone - growth is then rapid as extra food is converted to flesh. In areas having higher water temperatures phytoplankton production may be greatly increased - this will greatly affect the maximum fish biomass potential in a water (Payne, 1986).

Water temperatures are determined by three groups of factors:

i) *Meteorological*, e.g. air temperature, intensity and duration of solar radiation, incidence of snow cover and surface wind velocity. Various authors (Macan, 1958; Ward, 1963; Cluis, 1972; Smith, 1975) have shown that air temperatures are the dominant factor controlling water temperature and, apart from sites where thermal modification by effluent discharge has occurred or where the river flow is composed largely of groundwater, the agreement between air and water values is sufficiently close to enable air temperatures to be used as a statistically reliable predictor of water temperatures (Smith and Lavis, 1975). This is demonstrated for several sites in Britain (Figure 2.1) and Balarin (1987) shows temperatures for two sites in Malawi (Figure 2.2). Clearly solar radiation will only be effective on the epilimnion (nearest to surface zone) of larger standing water bodies. Though water circulation may occur in these bodies, on average deeper water in the hypolimnion is markedly cooler. Standing water bodies usually exhibit a wider range of both diurnal and seasonal temperature variations.

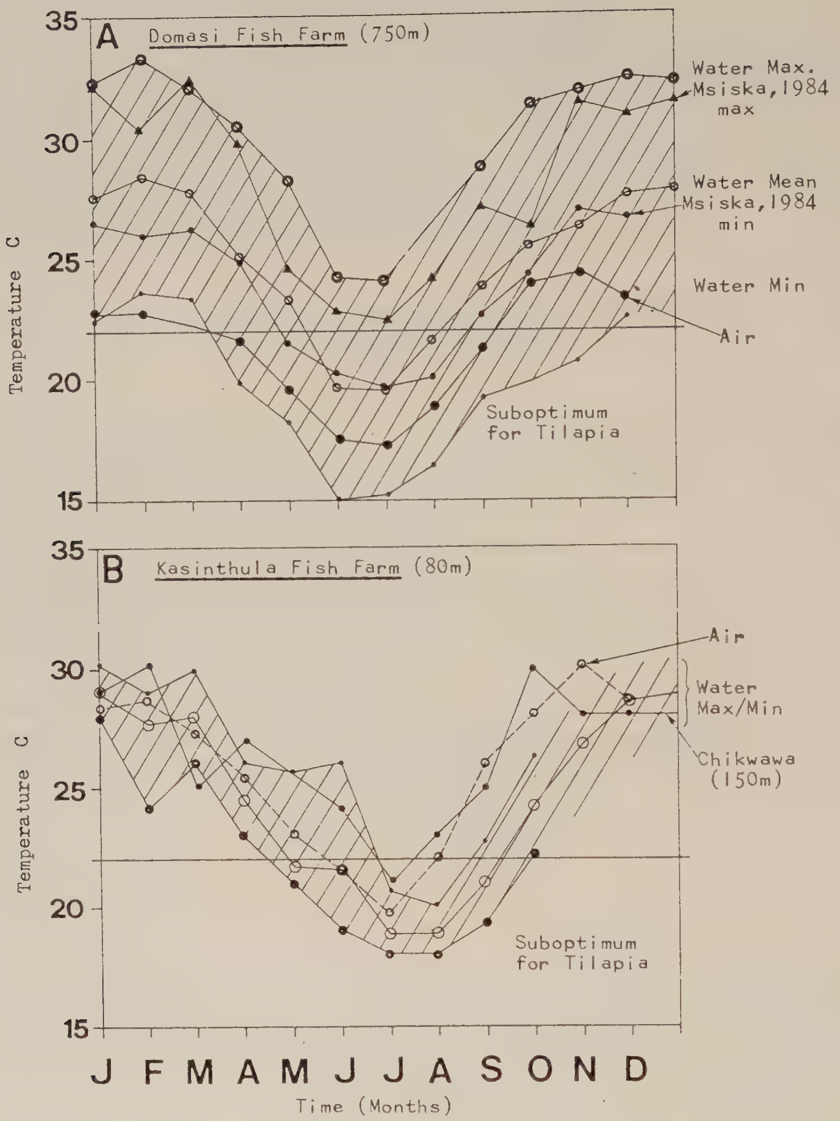
Figure 2.1 Relationship Between Air and Water Temperatures for Several Sites in Britain



ii) *Geophysical*, e.g. depth of water, volume of water discharge, degree of water mixing, height of banks and temperature of inflows. The temperature of stream inflow, or of the basal water flow, is the second most important influence on water temperature. Rivers which contain a large groundwater component have a small temperature range. Thus chalk streams or spring fed headwaters of many rivers may appear abnormally hot in winter or conversely cool in summer (Rodda *et al*, 1976). As a downstream progression is made temperatures are more influenced by the temperature of water from tributaries than by basal flow or by heat exchange from atmospheric contact.

iii) Human intervention, e.g. reservoirs and weirs, thermal effluent discharges and canopy alteration by logging or planting. As more of the world's rivers are being impounded, then temperature variations applicable to standing rather than flowing water bodies, become more common. Similarly, thermal effluents largely emanating from electricity generating plants

Figure 2.2 Mean Maximum, Minimum and Average Monthly Pond Water and Air Temperatures for Two Sites in Malawi

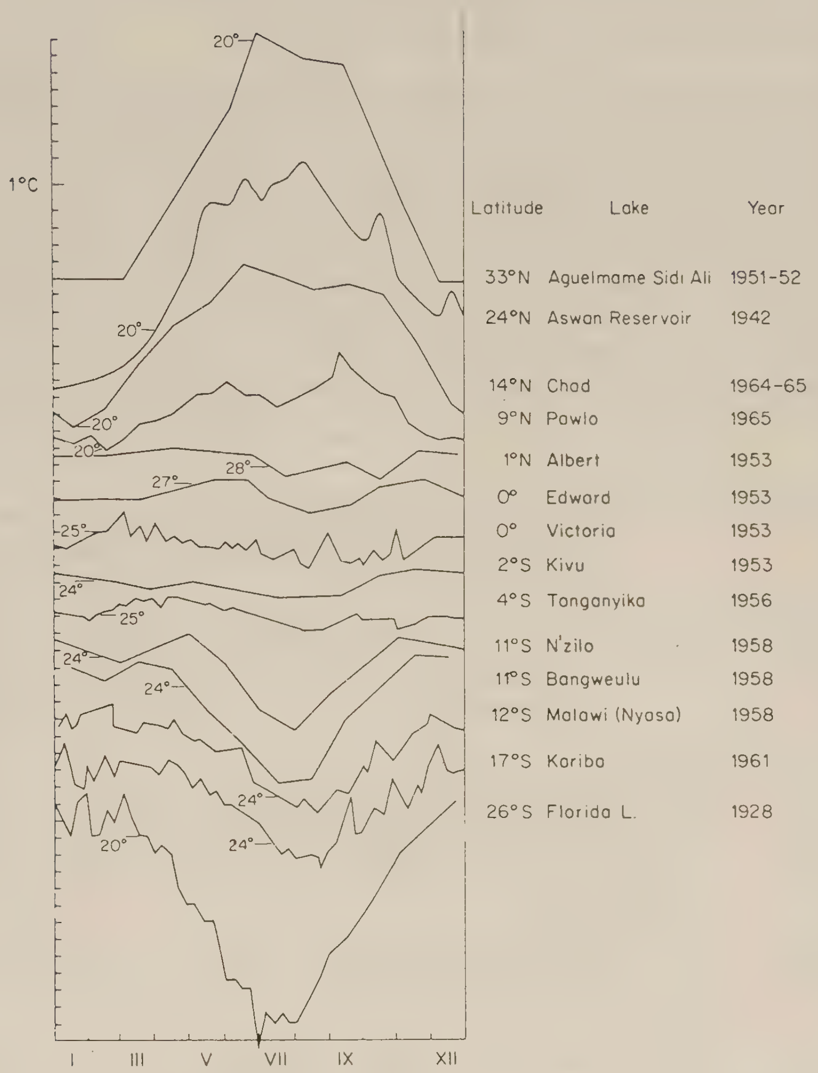


are increasingly encountered. Though heated water in some rivers may be dissipated quickly, or simply form a heated layer on the surface, in others the total effect may be quite noticeable.

There is very little chance of manipulating water temperatures on a commercial basis, though some intensive (mainly research) facilities are experimenting with production units which are totally enclosed in a polythene housing. Use can be made of the artificially heated water, e.g. at some power station sites the higher water temperatures can greatly speed up growth rates for various species.

The prospective fish producer should be aware that, at the macro-scale, the degree of water temperature variations will not be great - they will be related largely to latitude, altitude, season and the extent of basal flow. Figure 2.3 shows how the degree of variability of water temperatures varies with latitude for various African lakes or rivers (Talling, 1969). At the micro-scale the degree of variability would be more affected by those human intervention factors previously mentioned plus the size of the water body, the nearness to the source of the stream and the prevalence of inflows of tributary water. However, marked micro-scale variations are relatively rare since water readily mixes or adapts to achieve a temperature equilibrium in sympathy with ambient air temperature.

Figure 2.3 The Annual Variation of Surface Temperatures in a Series of Fourteen African Lakes



The annual variation of surface temperature in a series of fourteen African lakes, arranged by latitude. Successive curves are displaced downwards and the common temperature scale (left) refers to differences only. Absolute values can be located using the single temperature marked on each curve. (*Reproduced by permission of Schweizerbart'sche Verlagsbuchhandlung from Talling, 1969*)

2.3.3 Water Quantity

When considering water availability, the fish producer must be concerned not only with the total quantity normally available and potentially accessible, but also with the variability of water flow. It is impossible to state that "x" quantity of water will be needed over "y" period of time since the amount needed will vary according to:

i) The total volume of fish being produced.
ii) The density of stocking.
iii) The age, size or the species of the fish or aquatic organism.
iv) The temperature of the water.
v) The dissolved oxygen level of the water.
vi) The fertility of the water.
vii) The evaporation or seepage rates.

Generally, the larger the quantity of water available, the larger will be the size potential for individual fish growth and for total fish production.

The causes of water quantity variations at any particular location will be many. They will be a function of the temporal and spatial vagaries of the hydrological cycle at that location. Table 2.5 lists the main causes, noting whether they are primarily spatial variations or temporal variations (or both). The variability ratio of the water flow is of fundamental importance to aquaculture production. It represents the difference between a measure of high and low flows thus giving an indication of the consistency of flow expected. Areas having consistent flows will be less liable to flooding, will generally have less turbid water and the fish producer will be able to site gravity flow intakes with more certainty. Table 2.6 gives an indication of flow rate variability for nine selected hydrograph stations in England and Wales, and Figure 2.4 shows the frequency of flow variability for all 576 water gauging stations in England and Wales, both actually and cumulatively.

Table 2.5 Factors Causing Spatial or Temporal Variations in Water Availability for Fish Production

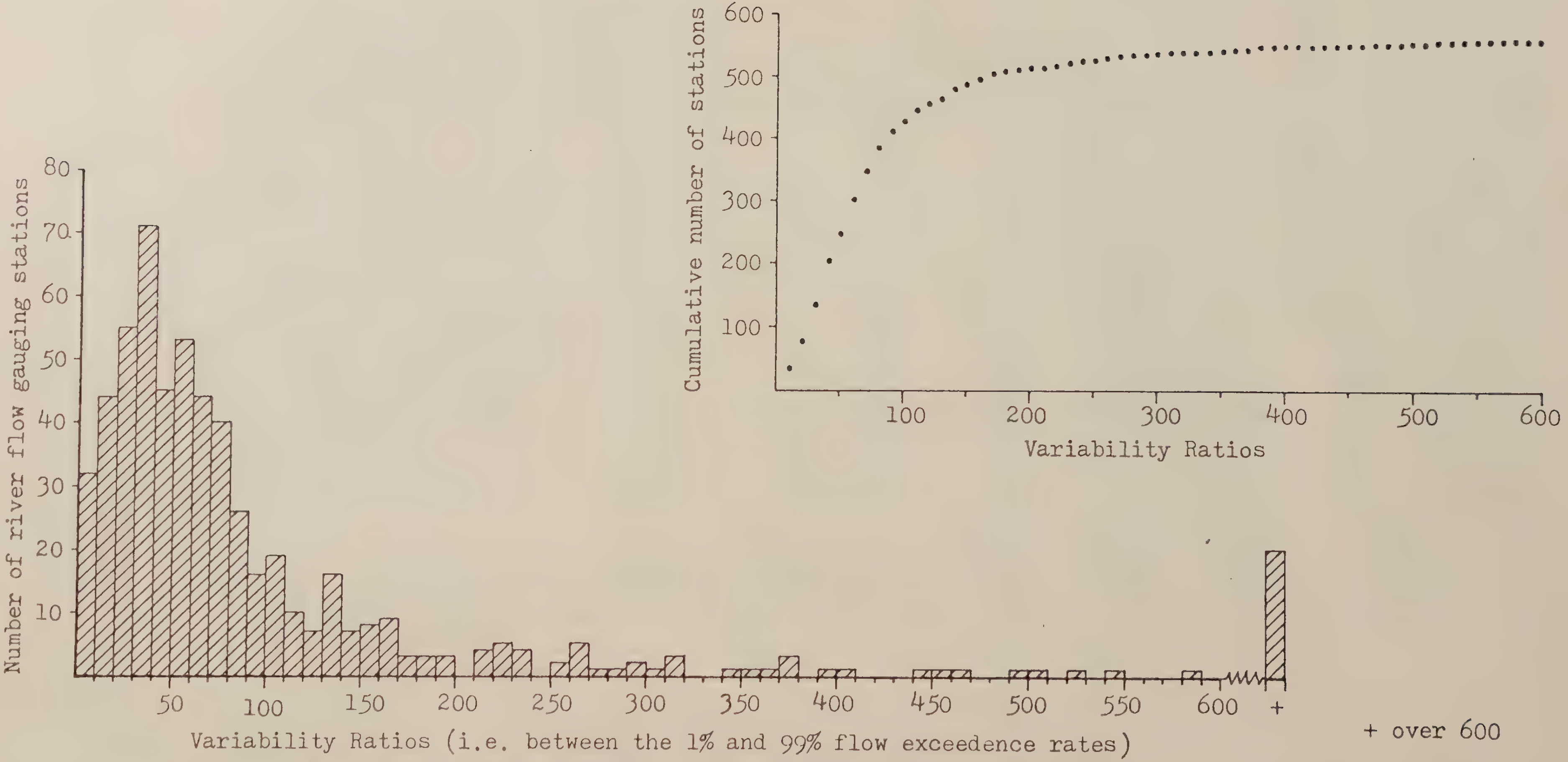
	FACTOR	SPATIAL or TEMPORAL
A.	Distance from the waterway source.	S
B.	Catchment size - affecting variability of river channel flow or lake size.	S
C.	Geological controls - affecting percolation or seepage rates.	S
D.	Soil type - affecting infiltration rates.	S
E.	Topography - affecting speed and amount of run-off.	S
F.	Precipitation - total quantity of, variability of and reliability of.	S & T
G.	Air temperature - affecting evaporation rate.	S & T
H.	Extraction of water - for industry, residential or agriculture.	S & T
I.	Extent of urban development - affecting rate and speed of run-off.	S
J.	Vegetation cover - affecting interception rates.	S & T
K.	Abstraction permits and restrictions.	S & T

Table 2.6 Flow Rate Variability for 9 Selected Hydrograph Stations in England and Wales

River	County	O.S. Grid Reference	Local Bedrock Conditions	Mean Daily Flow (cumecs)	Minimum Daily Flow (cumecs)	Percentage Minimum of Mean	Period Covered by Source Data
Itchen	Hampshire	SU449156	permeable	5.370	2.464	45.9	1959 - 1974
Bure	Norfolk	TG267198	permeable	1.074	0.383	35.7	1960 - 1978
Mimram	Hertfordshire	TL290130	permeable	0.522	0.135	25.9	1953 - 1978
Derwent	Yorkshire	SE707302	most imperm.	2.057	0.303	14.7	1937 - 1977(b)
Axe	Devonshire	SY262953	mixed	4.890	0.440	9.0	1965 - 1976
Avon	H. & Worcs.	SP034431	most imperm.	14.448	1.274	8.8	1937 - 1977
Usk	Gwent	SO345056	impermeable	26.782	1.607	6.0	1958 - 1978
Avon	Hampshire	SU145408	permeable	3.434	0.175	5.1	1966 - 1979
North Tyne	Northumberland	NY919706	mixed	19.739	0.000(c)	-	1960 - 1979

(a) All data was obtained from computer print-outs by the Water Data Unit at Reading.
(b) Excepting all of the 1940's.
(c) The Kielder Reservoir will prohibit the river drying up in the future.

Figure 2.4 Frequency of River Flow Variability Rations for All Gauging Stations in England and Wales



Wright (1974) has estimated that, in temperate areas having largely sedimentary rocks, geology and catchment size may account for over 90% of total flow variance, though in many mainly sub-tropical areas seasonality of rainfall will dominate. As a general rule water flowing entirely across, or which is mainly derived from, areas of permeable rock are likely to exhibit small variability ratios - typically in the region of 5 to 20. Conversely, streams which are dominantly on impermeable rock exhibit highly variable flow rates, with ratios of >200. This variability is frequently exacerbated by the coincidence of areas having high relief rainfall with areas having hard impermeable rock.

Under normal conditions, this function of water quantity can be readily controlled by the fish producer - FAO (1981) gives a detailed practical account.

Clearly, for inland fisheries, water quantity is seldom a problem in larger water bodies, with the notable exception of areas of inland drainage in arid, semi-arid or draught-prone regions, e.g. around the Aral Sea, Lake Eyre, Lake Chad, the Okavango swamp or the Nile marshlands of southern Sudan. For fisheries in reservoirs, or downstream from them, fluctuations in water area and level are important for their effect on biological production as well as the efficiency of fishing. Knowing the biology of the fishes and fishing techniques potentially provides the basis for managing flows to optimize fisheries, or at least to minimize losses.

For smaller standing bodies, the dry season evaporation potential is a limiting factor which is difficult to control. For producers utilizing flowing water, apart from periods of flow extreme, water quantity is readily adjusted by monk or sluice gates, and the land on flood plain or deltaic areas can frequently be modified (by excavation or impoundment) to provide a succession of ponds which can utilize large quantities of the parent river water.

Extremes of flow are of critical importance to aquaculture location. Excessive water flow, leading to flooding, can literally "wash" fish away and damage capital works, whilst periods of low flow usually coincide with periods of greatest water needs elsewhere, e.g for irrigation, and with enhanced evaporation. Here it is relevant to note that for some kinds of aquaculture it is desirable to achieve rapid water exchange, e.g. to increase oxygen throughput for salmonid production, whilst for other kinds it is desirable to limit water exchange rates, e.g to enable nutrient build-up which encourages plankton concentrations.

The actual variability of this production function over macro-scale space largely accords with the world's climatic zones, i.e. having regard to total precipitation, precipitation variability and evaporation rates. Almost all the low latitude tropical areas receive abundant convectional rain, though this has an element of seasonality related to changes in wind and pressure belts. Monsoon areas of S.E. Asia and higher coastal latitudes having prevailing westerly winds receive abundant rain water.

There will clearly be an overall tendency that - "The nearer the coast, the more water there will be available". Obviously rivers increase their size in this way; rainfall is usually higher here; plus the land will be lower and frequently flatter which encourages marsh, lagoons, etc. Estuaries will be wider and there will exist a diverse range of potential mariculture environments. Conversely, inland areas are more frequently deficient in water. Areas having been affected by Pleistocene glaciation frequently provide abundant water quantity, both because glacial erosive action has resulted in exceptionally long coastlines, e.g. Norway, Southern Chile and western Canada, and because land areas have been deeply scoured so as to provide numerous lakes, e.g. Canada and Finland. Areas receiving past or present tectonic disturbances, frequently have large standing bodies of water where down-faulting has occurred, e.g. the African rift valley.

Since water is confined to channels or standing bodies in a far from ubiquitous manner, then the variability of water quantitatively at the micro-scale is very large. Additionally, nearly all the factors shown in Table 2.5 show micro-scale variations which cause further spatial or temporal variability. And further to this there are many areas where there is still uncertainty as to even the existence or not of potential water supplies (Anderson, 1989; Shimang, 1989; Vincke, 1990). These factors all underline the immense importance of selecting for this production function when seeking production locations - Table 2.7 summarizes individual selection criteria.

Table 2.7 Summary of Spatial Considerations Relating to Water Quantity

a) The availability of data on maximum/minimum flow rates.
b) Have river flow rates been controlled since any past extremes of flow were recorded?
c) Check long-term plans on water abstraction policies.
d) Are underground water supplies obtainable?
e) The regulations regarding maximum permissible abstractions in area.
f) Throughput of water required either seasonally or for particular species.
g) The effect of evaporation rates on hot/dry season pond or lake levels.
h) The likelihood of gravity water flow being obtained.
i) Can water seepage losses be easily replenished?

2.3.4 Transport Accessibility

Transport costs *per se* frequently represent only a small proportion of total fish production operating costs, e.g. for trout production in the U.K., Lewis (1984) found that they were typically 5% and for shrimp production in Malaysia, Muir and Kapetsky (1988) reported costs of only 0.3%. However, accessibility to transport is important in a number of non-quantifiable ways (Edwards, 1978; Kapetsky, 1989).

Firstly, transport can be seen in terms of relative access advantages, whereby cost savings are made by selecting sites which have advantages of good direct access from the water side (or pond bank) to the public highway system. Since fish products are highly perishable, they are nearly all transported by road. This is because of the flexibility of scheduling and to prevent break-of-shipment costs associated with alternative forms of transport. Road transport is especially important if large-scale production is envisaged since necessary inputs and outputs could well be very bulky. Occasionally, usually in more remote areas, water transport must be considered, i.e. if it is feasible, cheap and there are few alternatives. Relative access advantages help to reduce vehicle running costs, expedite inward and outward deliveries and reduce personnel time/travel costs.

Secondly, transport can be viewed in terms of a cost function associated with distance between the production site and the market place. If markets are at a distance then transport penalties would necessarily occur. It is difficult to give likely cost/distance curves because these would vary as a function of total distance, condition of the roads, mode of transport, vehicle type and size, quantity transported, form of fish product (iced, frozen, fresh), etc. It is clear that in this sense many locations, especially in developing countries, suffer severe disadvantages, e.g. Lindquist and Mikkola (1989) show the potential problems of distributing fish products from Lake Tanganyika within both Zaire and Tanzania, and in FAO (1975) it was noted that the lack of transport routes presented a huge impediment to fish production development.

This impediment of the lack of transport routes highlights a third aspect of transport accessibility, i.e. should transport be viewed in terms of a cost, a distance or a time function? We noted that it is difficult to postulate transport cost penalties in site selection. Though distance penalties are easier to calculate, they too might give an incomplete picture, i.e. if the transport was slow, if break-of-shipment, a ferry crossing or any similar hold-up was involved. It could be argued therefore that time taken for transportation should be the norm used for assessing transport penalties, though this method too has some drawbacks.

There are several other ways in which transport accessibility might control fish production, and ways in which transport costs themselves could be controlled. If a site is selected which involves the construction of an expensive transportation connection, then this could well make the site non-viable (Muir and Kapetsky, 1988). In these cases viability might be dependent upon who was prepared to pay for construction costs, e.g. public or private or even co-operative funding sources. Transport costs themselves can be ameliorated by various co-operative buying or selling ventures, or by buying in bulk quantities. In some areas transport cost differentials have been eliminated entirely by suppliers adopting universal pricing policies on their products, i.e. irrespective of distance shipped.

The degree of spatial variability of this production function is strongly related to population density. Areas having a dense population are likely to have a correspondingly dense road network (or railways) and conversely rural areas will have few roads. Variations on this pattern are worth noting. Some rural areas have quite a high density of minor roads, i.e. where agriculture is important. There will frequently be a network of main roads which cross less densely populated areas in connecting major population centers. Fortunately for fish producers, many routeways choose to follow waterways since the formation of the waterways themselves have created relatively flat routes through areas which otherwise may be hilly. Also, access to water supplies for various purposes has always been a necessity. At the macro-scale there will be huge variations in transport accessibility, i.e. since it is a linear function, and there will also be qualitative variations in transportation provision. Table 2.8 summarizes the main transport criteria which need to be considered.

Table 2.8 Summary of Spatial Considerations Relating to Transport Access

a) The accessibility and regularity of scheduled transport.
b) What "fall-back" transport can be obtained?
c) Who might pay for installing new link routes?
d) The time/cost distances to various markets or urgent supply sources.
e) Is own transport provision necessary? If so, what?
f) Particular transport problems or considerations associated with specific locations.
g) Will break-of-shipment be required? If so, is this efficient?

2.3.5 Market Accessibility

In this section we will not be concerned with the form in which aquatic products are marketed, even though this form may influence markets served, e.g. in tropical areas fish may need to be disposed of quickly (usually locally) unless smoking, sun-drying or ice facilities are available to allow more distant markets to be served. There are many possible combinations and permutations in marketing linkages for the disposal of fish. Figure 2.5 shows a schematic diagram for the marketing of trout in England and Wales, and Balarin (1987) shows a diagram relating to markets in Malawi (Figure 2.6). Different flow diagrams would be appropriate in differing countries or regions, for different species, for different operational scales or at different temporal periods.

Figure 2.5 Flow Diagram Showing Table Trout Marketing Networks in England and Wales

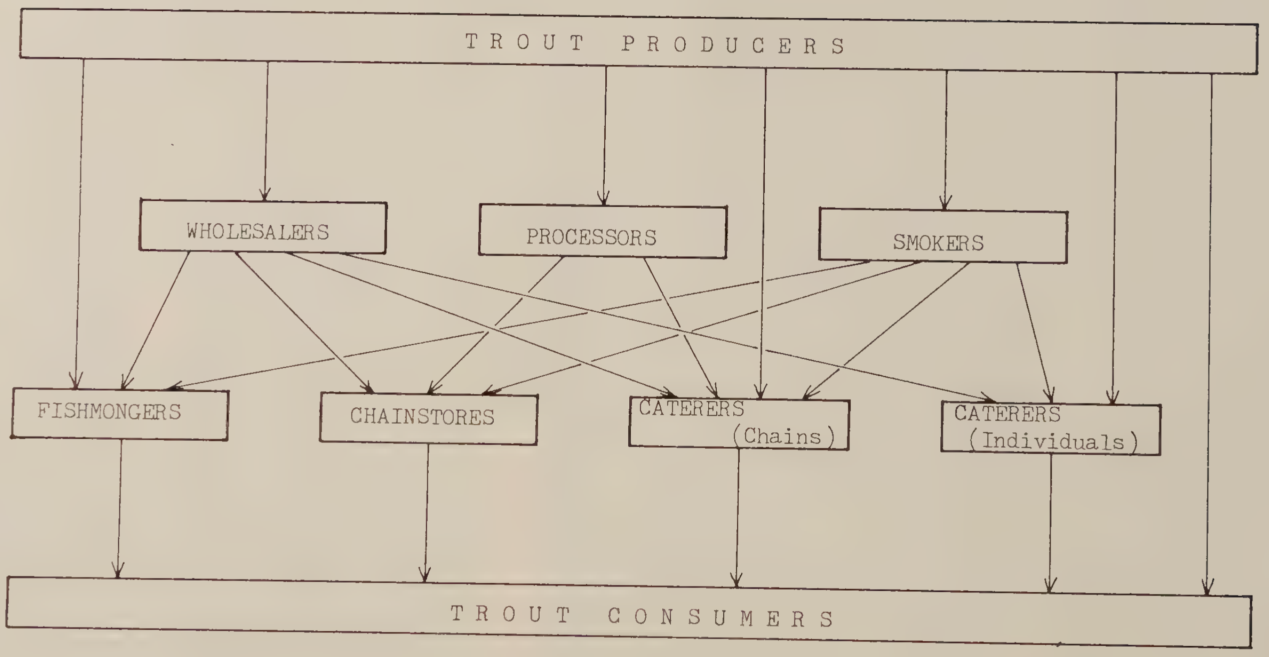
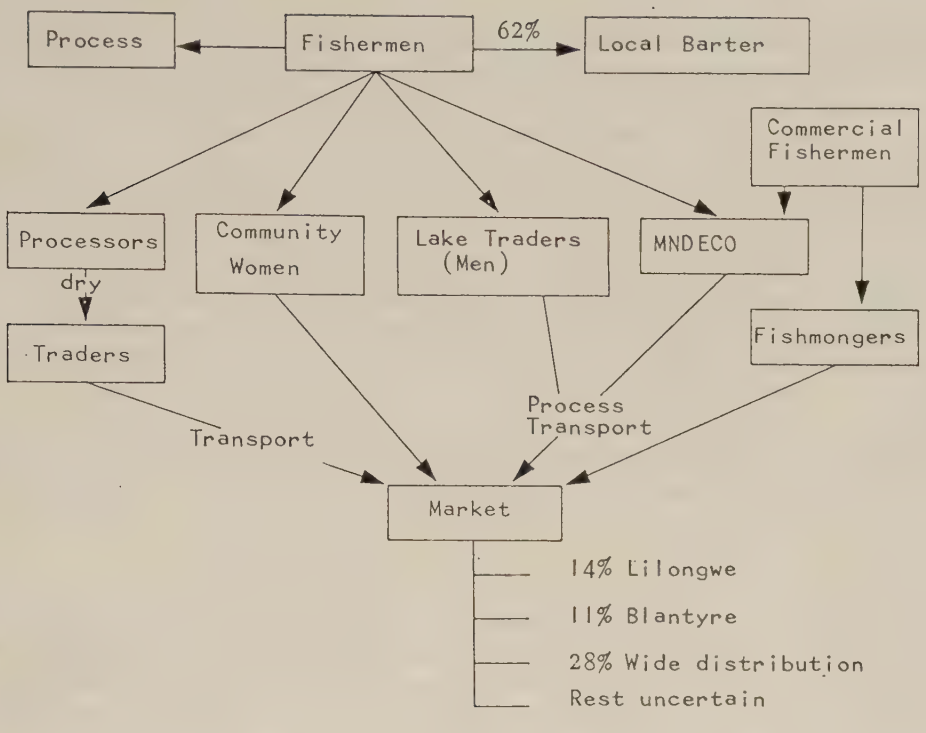

TROUT PRODUCERS
WHOLESALERS
PROCESSORS
SMOKERS
FISHMONGERS
CHAINSTORES
CATERERS (Chains)
CATERERS (Individuals)
TROUT CONSUMERS

Figure 2.6 The Fish Marketing System in Malawi



In most of the more developed countries the largest market outlets would be the wholesale sector. This might comprise of coastal or inland merchants, many of whom were associated with particular sources, e.g. a local fishing fleet, or with different aquatic species. There are often many merchants at each market center. Most fish handled would be fresh and purchase would be by day-to-day negotiations or by auction. Other wholesale outlets include fish processors, who would buy fish for freezing, canning or smoking. They often operate on a contract purchase basis and they might supply large retailers using particular brand names or they could be processing for export.

In order to achieve higher returns, many fish producers would endeavour to dispose of a high proportion of their production to markets which are "closest" to the final purchaser. Highest returns can be achieved by selling via the "farm gate" or at the "dock side" , i.e. direct to the public. Lewis (1984) has shown that trade can be obtained, often with considerable success, if there is a busy routeway passing by the production site (having appropriate parking). "Dock side" sales are only really possible where regular markets can be guaranteed at sites having public access. The next best return might be achieved by operating a fish delivery round or by selling to local hotels, restaurants, peddlers or caterers, i.e. outlets whose own "mark-ups" might be very high. Some larger producers have contracts to supply supermarkets direct and some might supply direct to fishmongers or other retailers.

An increasing volume of fish is being produced for live sale to supply various stocking or restocking waters. The natural reproduction rates of most fish species in many developed countries are no longer able to sustain the requirements for angling purposes, especially among the salmonid species. Periodic stocking to enhance food fisheries is common practice in much of Asia, particularly in China. Water pollution has totally eliminated aquatic stocks over large tracts of northern Europe and parts of north America, and where clean-up operations have been successful restocking has followed. This growth in serving the needs of leisure fishery is likely to slowly develop in many other parts of the world.

If fish production is operating in a free market economy, then there exists the potential to exert varying degrees of control over the market, e.g. by securing cost advantages through bulk input buying or by horizontal or vertical integration practices. The extent of these economic manipulations will vary according to various statutory controls, the size of the economy, the perceived investment rewards and the state of the economic climate. Because, at the present time, fish production is such a varied and complex economic activity, i.e. involving a risk element, much specialized knowledge and a large degree of commitment by the entrepreneur, then markets are not being dominated by large-scale fish producers.

Following the opening or closing of any fish processing market outlet, there can be quite dramatic changes in the advantages of differing locations for fish production. In a study of the spatial diffusion of catfish farming in the lower Mississippi area of the U.S.A., Meaden (1978) showed that the "center of gravity" of the industry changed quite noticeably during the 1960s and 70s, i.e. in response to the opening of new processing plants. The existence of any processing works is likely to be the focus of attention for many inland water fisheries. Transport routes or facilities can also determine the feasibility of using specific markets, especially in areas where fresh fish are demanded and/or where processing facilities are absent (Pathak, 1989).

Marketing information is now becoming more generally available, e.g. Satia (1989) shows how the fortnightly INFOPECHE bulletins, the bi-monthly INFOFISH INTERNATIONAL trade magazine and the GLOBEFISH (FAO) computerized data base are likely to have an effect on fish production and marketing strategies throughout Africa. A similar effect will be felt by the growth of specialized marketing organizations in other areas.

The degree of spatial variability of this production function varies quite significantly and can best be reviewed according to market outlet. Wholesale markets in most countries are distributed on a macro-scale. As indicated earlier they are mainly sited in larger cities or towns and in coastal or lake side fishing ports. Some countries may only have one or two wholesale centers, whilst traditional fishing countries might have many. As some wholesale centers, or particular merchants, specialize or deal in certain market sectors (or species) only, any prospective fish producer would need to be very certain where his nearest wholesale outlet was, i.e. if an increase in fish production materialize then an increasing proportion of output is likely to be disposed of via this outlet.

At a different marketing level, catering, hotel, restaurant or retail outlets would usually show a more dispersed spatial distribution, though clearly there would be many exceptions in remoter areas. Indeed in many countries, hotel or restaurant outlets would be confined to a few larger cities or resort areas. This market level will have a limited sales potential which is usually related to variances in disposable income levels within a region or country, or to variations in dietary preferences. It is likely that isolated market sites could only support the development of small fish farms since transport or storage costs would prevent further growth.

The spatial disposition of "farm gate" or "dock side" markets will clearly show no specific pattern apart from adjacency to urban areas, busy roads or fishing ports. Again the intended fish producer would be advised to investigate the possibilities for these outlets at individual locations.

For reasons previously given, the spatial variability of the stocking/restocking market sector will clearly relate to those waters which need extra stock. This will often accord with a combination of:

a) The degree of urbanization, reflecting a measure of the number of people likely to be fishing (anglers).

b) The degree of industrial reclamation, reflecting likely attempts to clear up water pollution caused largely by older industries which have been made obsolete, or reflecting areas of newer and cleaner industrial growth.

c) For recreational fisheries, the degree of affluence, reflecting the likelihood of having the ability to pay for recreation and to have the time necessary to participate.

d) For commercial fisheries, the perceived increased returns due to stocking.

In some smaller developed countries, virtually all of the country could satisfy these criteria, so restocking is very widespread. In larger developed countries which might have areas of sparse settlement, restocking markets would be more spatially variable. In most developing countries the amount of restocking is presently very limited, indeed in most cases unnecessary or non-existent, so the potential of this market sector would need careful investigation; Table 2.9 summarizes the main considerations pertaining to site selection relative to the markets.

Table 2.9 Summary of Spatial Considerations Relating to Market Accessibility

a) Distance to processing plant or other wholesale outlets.
b) Number of local retail outlets.
c) Potential for selling direct to final consumers.
d) Existence of local catering outlets - hotels, restaurants, etc.
e) Potential for contract supplying to shops or other larger outlets.
f) Availability of the means for preserving or keeping fish, e.g. ice, salt, etc.
g) Means of getting fish to market i.e. transport route and method.
h) Forms of fish product which are locally in demand.
i) Scheduling of production so as to meet temporal market demands.
j) Demand from, and location of, potential stocking markets.
k) The optimal production scale for servicing proposed markets.
l) The accessibility of marketing organizations or information.

2.4 Considerations of Some Other Spatially Variable Production Functions

Having shown in some detail the manner in which the major production functions control fish production, and how these functions might vary spatially, it will be apparent that the fact of spatial variability is of great importance in any decision concerning optimizing the production location. The intending fish producer, or any concerned person, will also be aware of the types of practical considerations which spatial analysts must make. We are now able to look briefly at some of the other spatially variable functions which control the complex enterprises of aquaculture and inland fisheries. Here again we will only concentrate on the ways in which the function might vary spatially.

2.4.1 Climatic Factors

Around the world there are well identified climatic zones and these have been intensively documented in most atlases and elsewhere. The main climatic problems to aquaculture or inland fisheries are associated with "unreliable" climatic areas. At the macro-scale these mostly accord with:

i) Areas where the timing of seasonal rainfall may be unreliable.
ii) Inland areas in the mid-latitudes where precipitation totals are unpredictable.
iii) Those usually warm areas which occasionally experience freak frosts.
iv) Areas having tropical cyclones, hurricanes, etc.

Micro-climatic variations would seldom cause problems to fish producers.

Prospective fish producers would need to be very certain of extremes in the temperature regime and be aware of the temperature tolerances of any species being produced. Excessive cold, leading to snow or ice, can cause access problems to production sites and severely impede the management of any waters (Cordell and Nolte, 1988b). Excessively high temperatures will lead to evaporation problems if water replenishment is difficult. Very heavy rainfall can, of course, lead to flooding, but equally importantly, both Sage (1980) and Kapetsky (1989) demonstrate that this is a major factor in lowering the pH of waters to sometimes dangerous levels. Heavy rain can also severely disrupt transport access. A lack of precipitation may lead to problems of water shortages which have been discussed in section 2.4.3.

2.4.2. Agglomeration

It is difficult to give a formal definition of what constitutes an agglomeration of fish producers, though it usually implies that some degree of cooperation is being purposefully obtained arising from the adjacency of production units. The size of agglomerations might vary greatly. The existence of agglomerations will give an excellent indicator of the suitability for fish production, since they are only likely to occur in areas which show outstanding production function mixes. The potential advantages to be obtained within agglomerations are:

i) The opportunity for bulk buying.
ii) Already established potential markets for the newcomer.
iii) The sharing of transport costs, particular pieces of equipment or facilities or knowledge.
iv) The likelihood of a nearby processing plant being established.
v) The opportunity for fish transfers to meet particular customer orders.

The prospective producer would need to find out whether agglomeration advantages were actually functioning as a positive factor. It might in fact be better to site at a distance from other producers, i.e. even if sub-optimal conditions existed, in order to have less competition or to supply a previously untapped market. It might also be the case that the area has sufficient producers, i.e. from the considerations of water quality and quantity, markets saturation, potential site availability, disease risks, etc.

2.4.3. Soils

Soils will vary greatly at the macro-scale because soils result from complex physical interactions which themselves take place in areas having different topographic, geologic, climatic, vegetation and human influences (FAO, 1985). Geology often gives a clue to soil type suitability since it indicates the parent rock, and topographic studies help since they reveal steeper slopes and hill tops where soils are invariably adverse. These studies will also indicate river flood plains, deltas, estuarial locations and coastal plains where promising alluvial soils are likely to occur. Kapetsky (1989) and others have illustrated how soils may vary greatly at the micro-scale. This makes it essential that the intending fish producer be aware of the particular properties of soil as they apply to the suitability for aquaculture. The main properties are shown in Table 2.10, though FAO (1985) should be consulted for further details. The producer should also be aware that soil types may vary with depth, and that it is useful to know where accessible soils maps are. If soils are deficient at particular locations, then there are means of controlling or manipulating these though they too will exhibit spatial variations, e.g. by bringing in quantities of a suitable soil, by liming, by adding organic materials, by lining ponds with plastic sheeting, by puddling, by adding fertilizer or even by constructing alternative production systems.

Table 2.10 Index Properties of Soils for Freshwater Fish Culture

SOIL TYPE	Odour[2]	Colour — mottling	General texture	Particle-size analysis (L)	Shaking test[3]	Dry consistence	Moist consistence	Liquid limit — plasticity (L)	Plastic limit — plasticity (L)	Structure	Permeability — field	Coefficient permeability (L)	pH (L)
TESTS YOU CAN MAKE YOURSELF	●	●	●		●	●	●			●	●		
Sand, gravel		●		●									
Inorganic silt		●	●	●	●	●	●	●	●	●	●	●	●
Inorganic clay		●	●			●	●	●	●	●	●	●	●
Loess		●	●	●	●	●	●	●	●	●	●	●	●
Organic silt	●	●	●	●	●	●	●	●	●	●	●	●	●
Organic clay	●	●	●			●	●	●	●	●	●	●	●
Peat	●	●	●										
Composite soil[1]	●	●	●	●	●	●	●	●	●	●	●	●	●

(L) = Laboratory test

[1] Particle-size analysis on total sample; particles are then separated by size into two groups; the tests for "sand" are performed on the group with particle size larger than 0.075 mm and the tests for "silts" are performed on the group with finer particles

[2] A faint odour may be intensified by slightly heating the sample.

[3] See Section 60.

2.4.4. Relief (Topography)

Though this function may vary greatly at both the macro and micro scales, over significant proportions of most regions relief will not pose a barrier to fish production. The main problem areas will be of two types:

i) *Excessively flat areas*. Here flooding, plus the inability to provide for a gravity flow of water and poor drainage, may be the major problems. Additionally, sluggish water flows found in flat areas are associated with low dissolved oxygen levels, high summer water temperatures and, near coastal areas, saline intrusions.

ii) *Areas having steep slopes*. Here enterprise sites may be difficult to locate and develop, and any adjacent flat waterside area would be prone to spate flooding conditions. Areas of steep relief may also cause problems with other production functions such as transport accessibility, isolation from markets, high rainfall and run-off, etc.

Underwater relief, i.e. bathymetry, can also be important. For example, in shallow areas water circulation is restricted under cage installations. In deep waters, anchoring costs for raft culture can be high.

2.4.5 Land costs (or Rent)

It is impossible to state actual land costs or rents for any general location since constant spatial and temporal adjustments occur. However, land cost variability will usually be a function of three factors:

i) The supply of, and demand for, land - as reflected by population density.
ii) A perceived regional economic potential - as reflected in commercial investment.
iii) Land quality - as reflected by land use capability or perhaps soil quality.

There would generally exist a strong positive relationship both between land costs and each of these three factors, and between each of the three factors *per se*, e.g. areas would tend to be densely populated precisely because land quality was good or because perceived economic potential was high. At the micro scale, any of the three factors could prove dominant in a particular location and at this scale there would be large cost variations over quite short distances. At the macro-scale the land cost surface would be much more smoothed. Actual land costs or rent will vary depending on factors such as whether the land is owned or rented, what its alternative use value might be, how much land is needed, etc. Additionally, most waterside land can command premium prices because of the huge range of competing uses.

Although the initial cost of land may be a major item of expenditure, and it may therefore greatly affect the location decision, it can be insignificant when costed over a long period. The fish producer should be aware that, since a hypothetical location-economic rent curve would show that future income expected from fish farming, rather than most other types of farming or rural land use, would be advantageous, he could afford to pay more per unit of land.

2.4.6. Availability of Credit (or Capital)

In developed countries there are few spatial variations in access to credit. Limitations are related to personal factors concerning the entrepreneur, plus perceptions of aquaculture as a risky enterprise, whose costings may be hard to assess because of output quantity and pricing uncertainties, and because of temporal delays in achieving any returns. With dwindling stocks being available to inland fisheries, it is likely that capital for future developments here will be hard to obtain. In less developed countries credit or capital may be very difficult to obtain and very high interest rates are common. Part of the reason is that aquaculture is relatively new. Consequently, bank loan officers are not well informed on techniques of assessing the economic viability of fish farming. The likelihood of obtaining credit would vary spatially, with urban oriented locations finding it easier.

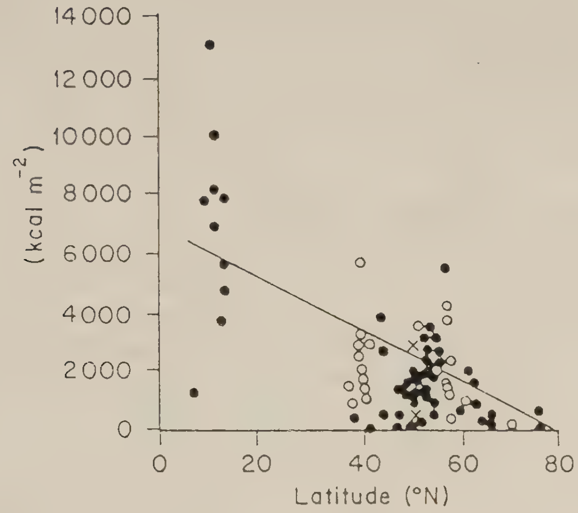
The prospective fish producer should seek funding from not only traditional commercial/banking sources but also from various organizations specially established to help with financing development projects, e.g. EEC. loan funds; various UN funding programmes; government funds to help diversify local economies; regional development schemes; fishery development organizations and various development agencies. Balarin (1987) lists nearly twenty different agencies, etc., who were providing external assistance for fishery projects within Malawi alone. He also shows how financial assistance may be given for various facets related to fish production, e.g. personnel training, demonstration farms, R.& D. projects, etc. Other credit sources are cited in various FAO documents e.g. Baluyut (1988); Girin (1989); Pathak (1989); Satia (1989). The potential producer would do well to seek both documented sources which reveal funding availability and advice about the appropriateness of any desired investment. Since costs of capital items (plus labour) may vary spatially (and indeed non-spatially), then several alternative costing estimates should be sought and some idea gained as to the relative cost advantages of different areas.

2.4.7. Availability of Fertilizer and Agricultural By-Product Inputs

The natural fertility of water varies greatly as a function of the complex interrelationships between a number of environmental factors, e.g. available nutrients in the soil, strength of solar radiation, water turbidity, depth of water, etc. Maar *et.al.*(1966) give a simple explanation of this. Variations in natural fertility could well be discussed as a separate production function but, since it is readily manipulated and since some of the other functions we have reviewed may control natural fertility, we will look only at the availability of fertilizer inputs *per se*.

Fertilizer inputs are frequently not even considered in cooler areas because plankton growth rates will be much slower meaning that better (or more cost-effective) results can be achieved by supplementary feeding (see Figure 2.7). This logic may also apply in warm water areas where intensive, highly capitalized production systems operate.

Figure 2.7 Relationship of Phytoplankton Production During the Growing Season to Latitude (from Brylinsky and Mann, 1978)



The distance from farms having livestock is obviously of importance to the spatial availability of fertilizer, i.e. since animal manures are optimal, especially poultry manure, and therefore the incidence of these sources will need researching for any specific location or area. There will be large cost variations in acquiring fertilizers because of variations in its quality, the amounts available seasonally and transport cost efficiencies. In many areas, e.g. much of Africa and southern Asia, there is a distinct lack of fertilizer even for more normal agricultural use (Satia, 1989).

The balance of fertilizer inputs must be carefully considered, i.e. both the economic balance, involving cost of inputs v. extra outputs obtained, and more importantly the environmental balance such that maximum productivity is obtained but not too much fertilizer is added which will lead to water quality deterioration. This balance (in both senses) will vary temporally and spatially. The type of production system will influence the demand for fertilizer, e.g. where water exchange rates are high then fertilizer inputs will be less effective, as will inputs made to very large bodies of water. The fish producer might wish to consider the viability of polycultural systems as a means of supplying fertilizers, e.g. by combining ducks and fish, or by integrating crop rotations with fish production in dyked fields so that residues from the cropping cycles help fertilization. If natural fertilizers are unavailable the producer might need to consider the economic viability and spatial availability of inorganic fertilizers or supplementary feeds. Palm (1989) gives an excellent summary of variations in fertilizer needs.

2.4.8. Availability of Extension Services

The actual provision of this function, in one form or another, exists in most countries but the number of extension workers would closely correlate with the wealth of a country, or with its interests in fish production, e.g. Baluyut (1989) reports a well developed network throughout much of eastern Asia, though with insufficient workers in the poorer areas of Laos and Vietnam, and Satia (1989) notes that extension services are insufficient in most of sub-Saharan Africa. This lack of extension services in most developing countries means that the availability of this function is spatially poor and probably "patchy". A major problem for areas having few extension workers has been their lack of spatial mobility, though this is now being rectified in many countries. In developed countries this function could be looked upon as being almost ubiquitous, i.e. in the sense that they would nearly always be on a fairly short service call. The provision of extension services in ten major countries has been well documented in Chakroff (1981).

Prospective producers would do well to not only familiarize themselves with formal extension service provision in selected areas, including likely temporal delays in receiving advice, as well as the quality of the information being provided, but also to seek out alternative arrangements regarding sources of aid and information. This might be from neighbouring producers; from farmers unions; from veterinary sources; from trade journals or magazines; from "Peace Corps" workers in many countries or from aid agency officials, etc. Some degree of self education in fish production methods and problems would appear to be quite vital, especially in those areas which are likely to be in temporal isolation from the extension service.

2.4.9 Current Inland Fishery Levels

It is difficult to work out exact levels of fishing which may be possible, especially in tropical areas, because this depends on the natural fish biomass production rates, which in turn depend on a large number of variables (Payne, 1986). The levels of potential fish procurement will also vary spatially depending upon the type of fishery environment - lake, river, estuary, etc. Though some fisheries have possibly not yet reached their maximum sustainable yields, e.g. many river fisheries in Latin America and Africa could support higher fishing levels, with rapid population increases in these areas this is increasingly rare. In much of the rest of the world, current fishing levels are already too high and most countries are adopting restrictive measures in order to conserve stocks.

Controls over fishery levels can be realized in several ways:

a) Statutory quotas for fishermen, boats, species, etc., can be laid down.
b) A closed season can be stipulated.
c) A minimum fish size per species can be ordered.
d) The number of lines, nets, boats or fishermen can be limited by licence or taxes.
e) The size of the net mesh can be adjusted.
f) Given areas of water can be excluded from fishing for various time lengths.
g) Natural stocks can be supplemented by fish "ranching".

Many of these measures may be very difficult to regulate, especially when the fishing effort is distributed around a large water body. In practice, much fishery regulation is accomplished by traditional authority. Central governments may have laws on the books, but often the political will and personnel are lacking for enforcement.

2.5 Other Production Functions Showing Some Spatial Variability

Having now examined a large number of production functions in varying degrees of detail, the prospective fish producer or land holder will at least be conscious that the simple fact of having some accessible water nearby may not be good grounds to embark upon fish production. Likewise, the fishery planner will know that a variety of criteria will have to be taken into account to properly identify the areas with the best prospects for success in fishery development. In any case we have only reviewed some of the major functions which vary spatially. Table 2.11 shows a large number of other functions which vary in this way and which might also need to be considered before a suitable site could be selected.

Table 2.11 Further Production Functions Which May Show Spatial Variability

a) Distance from the source of a waterway.
b) Areas having dietary taboos or food preferences.
c) The relationship between income levels and fish protein costs.
d) The relationship between fish costs and competing meat protein costs.
e) The distribution and availability of underground water sources.
f) The existence of areas designated for other specific activities.
g) The existence of shelter for cage culture.
h) The bathymetry for cage culture and fish netting.
i) The presence of particular "ideal" environments, e.g. mangroves.
j) The availability of eggs, fry, fingerlings, etc.
k) The availability of energy sources.
l) The availability of skilled labour.
m) The availability of supplementary feed stocks.
n) The availability of relevant equipment.
o) The prevalence of endemic, water borne diseases.
p) The prevalence of predators.
q) Salinity levels in estuaries or mangroves.
r) The social acceptability of aquaculture as a food production system.

CHAPTER 3 - OBTAINING DATA FOR SPATIAL DECISIONS

3.1 Introduction

In order that the potential fish producer can select a site, or choose a general location from where a specific site may be selected, then he must have the necessary information telling him the manner in which individual production functions vary spatially, and preferably how selected optimum combinations of these functions vary in "space". The collection of this information will be one of the most essential activities in the spatial decision-making process, especially in view of the paucity of spatially referenced data in many countries. Indeed, it is now being noted by some involved specifically in GIS (Worrall, 1989) that too little attention is being given to improving data collection techniques, i.e. as a means of improving the quality of the data obtained. Information (or data) would normally, and most usefully, be presented in one of a limited number of ways i.e. as maps, tables of statistics, reports or in graphical form. Since each of these formats must have been compiled from data which were assembled in various ways, it is the concern of this chapter to outline the main ways in which data is acquired, i.e. not the ways in which it is finally mapped.

Figure 1.3 indicated that data could be conveniently sub-divided into the following categories:

i) Primary (directly sensed) data.
ii) Secondary data.
iii) "Proxy" data.
iv) Remotely sensed data.

Though we will use these four categories, the treatment of the subject matter within each will be rather different, for reasons which will be made clear, and this will greatly effect the amount of space devoted to each and the degree of detail given in some sections - indeed remote sensing will form the subject of a separate chapter.

3.2 Obtaining Primary (Directly Sensed) Data

We cannot explain here the detail of each of the primary techniques involved, mainly because many readers will already be familiar with them, and because there are available numerous authoritative works on the techniques involved in primary data collection. However, since worldwide there are so many potentially promising geographic areas for aquaculture and inland fisheries, about which there exists little or no data, and since in many cases this data would be easy to collect, we shall offer a range of ideas for using primary data collection techniques, i.e. which are relevant to site selection for aquaculture or for the management or development of inland fisheries.

The volume of primary data that can be collected for any specific piece of research, or for any particular site, will be a function of many variables, the important ones being:

i) time availability,
ii) capital outlay allowed,
iii) skills and number of personnel involved,
iv) amount of secondary data already available,
v) the mobility of collectors,
vi) size of the area being studied,
vii) terrain of an area,
viii) the equipment available.
ix) and the overall accuracy and precision required of the results.

However, since resources are usually limited, primary data collection will frequently be location specific and a comprehensive view of an area will seldom be obtained. The actual data acquired from primary data collection will be in several forms, e.g. numeric, digitally encoded, photographic prints, labelled pictorial, written descriptions, colour or key coded spatial. In its raw state it may have little use but most of it will lend itself to transformations. These will include:

i) Forming the bases for topographic, thematic or derived maps.
ii) Being used as textual or illustrative material in journals, books, reports, etc.
iii) Being digitized for convenient storage and later use.
iv) Being converted into statistical or tabular form.
v) Being shown in various graphical forms.
vi) Editing to form a documentary/visual display (film or video).

3.2.1 Techniques for Collecting Primary Data

Primary data collecting consists of acquiring various types of "original" data by a number of personal or direct methods and techniques. The origins of all published information must have been from various types of primary investigation. It is possible to propose a rather crude typology of primary data collection (Table 3.1). Within each of the technique headings shown there would be specific sub-categories of primary data collection, each applicable to the particular area of research being undertaken. Each of the techniques will encompass a wide degree of sophistication, e.g. for both measurement and photography a range of instruments can be used, and for some techniques it is possible to acquire a high degree of skill, e.g. in field sketching. For all of the techniques there are recognized rules or conventions which are devised to operate within a scientific or objective framework so as to ensure degrees of detail, accuracy, consistency, etc. Most of these primary techniques require that some preparatory work is undertaken, so that aims and objectives are clear, that equipment is available, so that a timetable can be met and so that data recording can be easily made. Since it is impractical to completely cover an extensive area by any of the techniques, various sampling methods will need to be employed.

3.2.2 The Application of Primary Data Collecting Techniques to Aquaculture and Inland Fisheries

3.2.2.1 Direct mapping and field sketching

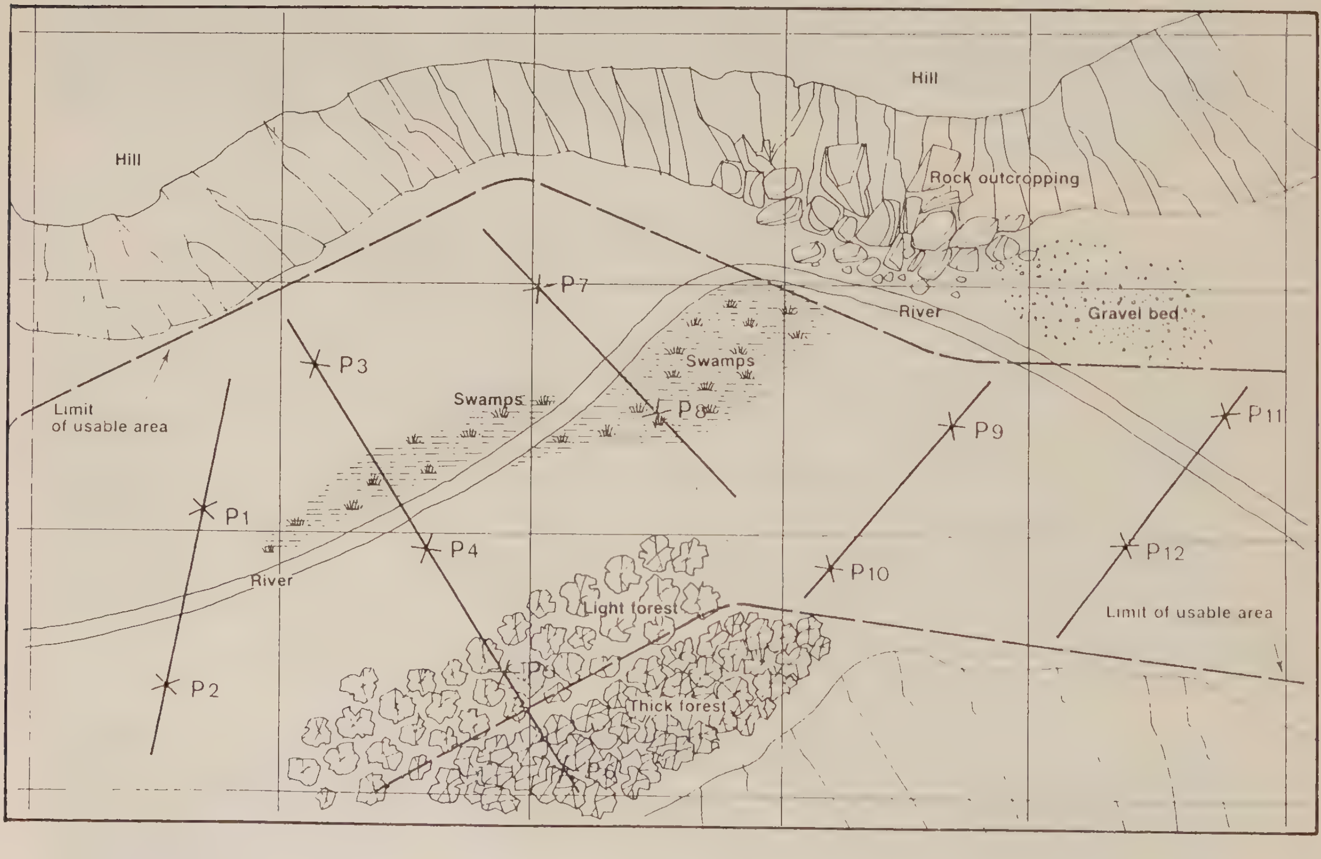
These two techniques can be considered together since they have many similarities and they would be used to gather data on the same production functions. These techniques could be used to locate where conditions were either particularly advantageous or particularly difficult, e.g. steep slopes, dense woodland, cliffs or points where a gravity flow of water could be obtained. Mapping could also indicate locations or points which could be used for particular purposes - in fact, unless very good and up-to-date maps or plans already existed, it would be almost essential to carry out one or other of these techniques for any selected site.

Figure 3.1 (from FAO, 1985) illustrates a typical field sketch of a stretch of river - this has been overlaid by a series of transects along which it is intended to measure soil quality. Any sketch maps could be later transferred to higher quality hard copy or could be improved and then digitized. The user would need to be aware of scale and to have a prepared key. The advantages of using these data collecting techniques are that they are inexpensive, though they are impractical for large areas or sites unless a large number of personnel were available.

Table 3.1 Techniques for Primary Data Collection

TECHNIQUE	COMMENTS
Direct Mapping	Consists of spatial recording of visible features of the landscape, usually by means of coded categories.
Photography	Includes still photography, video recording and various kinds of air photography.
Field Sketching	Allows scenes to be drawn and annotations to be added referring to important features.
Interviewing	This may be face to face or by telephone.
Questionnaires	Several important techniques exist each of which can be verbally administered or carried out by post.
Measurement	This involves the recording of numerically assessed data, on various measurement scales, by the use of any of a large array of instruments.

Figure 3.1 Sketch Map Used to Assess Environmental Quality and Soil Sampling Points


Hill
Hill
Rock outcropping
River
Gravel bed
P7
Swamps
P3
Swamps
P8
Limit of usable area
P9
P11
P1
P4
P10
P12
River
Light forest
Limit of usable area
P5
Thick forest
P2
P6

Note: each square is 100 x 100 m or 1 ha and the total usable area is about 7.5 ha.

Note: when you have different kinds of vegetation such as cultivated land, pasture, open savannah, forested savannah, and light and thick forest area, plan your reconnaissance survey so that you obtain soil samples from each of the different vegetations. You can eliminate areas from your plan with large surface stones, gravel beds or rock outcroppings which are unsuitable for earth-pond construction. Most thickly forested areas can also be considered unsuitable.

3.2.2.2 Photography

By far the most important use is aerial photography but since this is rarely a primary data collection technique carried out purposely for aquaculture or inland fisheries site selection, we shall refer to it along with remote sensing under section 4.4. Ordinary still photography would have few uses other than those mentioned for direct mapping or field sketching. Although ground based photography is also only really viable on a comparatively small scale, video filming is increasingly important since the images can be replicated and shown later to those parties who might be interested in site selection *per se* or in the viability of particular projects. Similar advantages and disadvantages exist as for direct mapping or field sketching, though camera costs could be very high.

3.2.2.3 Interviewing

Along with measurement, this is perhaps the most important data collection method. In practice interviewing could help to obtain spatially related information on any production function. Typically, fish farmers are interviewed about management practices, yields and production costs. Fishermen are questioned about catches, gear, operation costs and processing and marketing outlets. This method is enhanced if local experts can be found who can assess the reliability of the responses and who can establish a rapport with the persons being interviewed. Such interviews are particularly valuable if they have the initiative to bring out aspects of spatial information not originally foreseen, but ultimately important for the outcome of the study. For example, various factors relating to a chosen area, e.g. local fishermen frequently have detailed knowledge on local fish habits, climatic factors, water quality, etc. Other people are experts on markets or marketing, on financial matters and credit availability or on the types of advice which might normally be provided by the extension services - though an interview with any existing extension or local fisheries officer before reaching a location decision would seem advisable. Some location factors, such as the availability of underground water, the prevalence of endemic disease and local transport availability, can only be reliably obtained by interviews or personal contact.

There are few particular advantages with this method except that in many cases, as suggested above, interviews can lead to finding out about alternative information sources or important unforeseen problems. The disadvantages are that data obtained might be subjective and it could rarely be converted to mappable or statistical form.

3.2.2.4 Questionnaires

Although questionnaires can only help with the assessment of a limited number of production functions, they may be the only means of finding out about certain important data. Local food preferences can be found out by questionnaire, and fish producers in a given area can be questioned as to their perceptions of the relative importance of each production function to the success of their enterprise. Some marketing information is best found by questionnaire, e.g. which markets will take which kind of fish product, and a survey of fishery officers may indicate details on restocking locations.

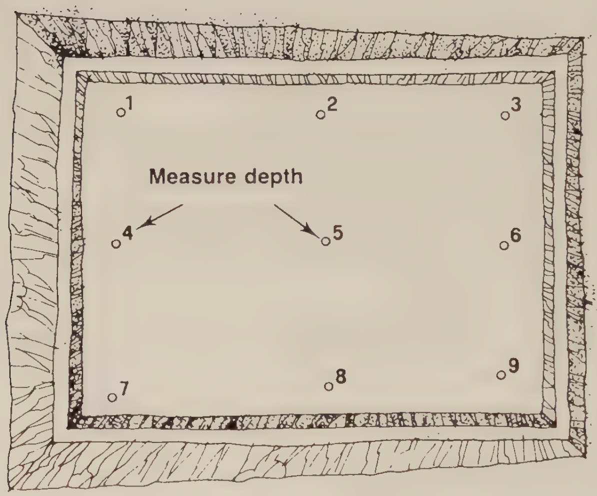
Providing that a significant proportion of responses are received then questionnaire techniques have a number of important advantages:

i) They are comparatively inexpensive.
ii) They are adaptable to sampling techniques.
iii) The data collected can readily form the basis of statistical or graphical information and can sometimes be incorporated into maps.
iv) Questionnaires can be structured so as to find out exactly the information required, i.e. existing secondary data may not include this.

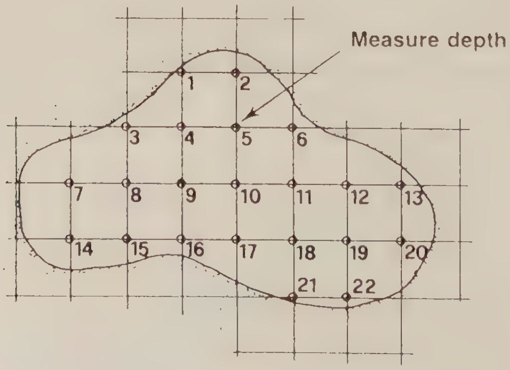
3.2.2.5 Measurement

The various measurement techniques could be applied to many functional categories, using an assortment of levels, i.e. nominal, ordinal, interval and ratio scales. Most spatially variable aspects relating to water quality or quantity can be readily measured. Figure 3.2 illustrates two practical ways of measuring water depth - it is taken from FAO (1981) which details all aspects of water quantitative measurements. Other area and yield measurement practices are defined in Petricevic (1988). Soil and water quality parameters are easily measured using various simple techniques (see FAO, 1981 and FAO, 1985). Figure 3.3 gives an example, using several types of measurement, of a data collection survey form designed to give some indication of the overall environment for life along a surveyed stretch of river. Although climatic factors can be measured easily, it may not be worth doing so since valid data needs to be recorded over a considerable time period (perhaps 30 years) and since data on average and extreme conditions can be readily obtained for most areas.

Figure 3.2 Methods for Measuring Water Depth in a Pond or Reservoir



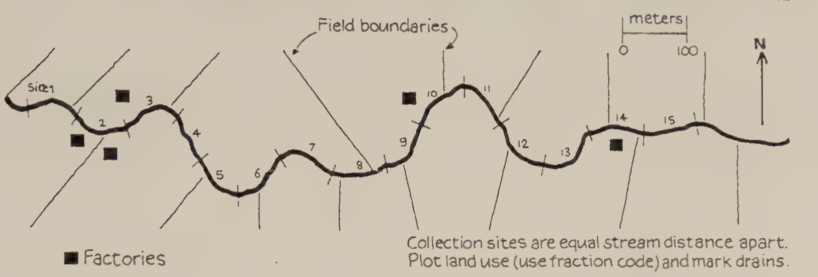
$$\text{Average water depth} = \frac{1+2+3+\ldots+9}{9}$$



$$\text{Average water depth} = \frac{1+2+3+4+\ldots+22}{22}$$

Figure 3.3 Sample Work Sheet for a Stream Survey

Pollution survey map ____________ Date ________ Time ________ Stream ____________ Students name ____________



Collection sites are equal stream distance apart.
Plot land use (use fraction code) and mark drains.

	TRE	TDS	SS	BOD	Flow rate	Appearance	pH
Site 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

Indicator animals

	Mayfly		Stonefly		Potamopyrgus		Chironomid		Bulinus		Psychodid		Tubifield		Nil	%
	No.		No.		No.		No.		No.		No.		No.			
Site 1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																

TRE = Total residue on evaporation
TDS = Total dissolved solids
SS = Suspended solids
BOD = Biological oxygen demand

The obvious advantage of primary measurement is that site specific data can be obtained. A disadvantage is that several of the measurements would need to be carried out over an extended time period, e.g. water temperatures, and others might be highly variable from day to day, e.g. some water qualitative factors and water volume. Measures such as bathymetric depth and soil quality would be relatively constant. Some measurement techniques could involve rather complex or expensive equipment.

3.3 Obtaining Secondary Data

Since all secondary data only represents primary data which has been converted into a more accessible form, and since the actual venues for obtaining most data are mainly self-evident, e.g. libraries, government offices, book shops, private and public organizations, etc., then our concern with obtaining secondary data can be quite short. In this section we will only briefly concern ourselves with three things:

i) A summary of the format and sources for some secondary data.
ii) The production functions which secondary data can best provide information on.
iii) Sources of secondary data for mapping purposes.

3.3.1 The Format and Sources of Secondary Data

We will briefly allude to the format and sources of secondary data since these are vital to the compilation of the two important methods of assessing location suitability, i.e. via maps and GIS. The format of secondary data takes several basic forms:

i) Written accounts - descriptive, explanatory, analytical.
ii) Diagrams, figures, pictures, photographs or maps - all graphical perceptions of reality.
iii) Tables, graphs or statistics - quantified summaries of real world data.
iv) Digitally encoded material - for computer use.

Within these four broad categories there are numerous sub-categories. Though any of the formats could be published by themselves, most secondary data relevant to location decision-making would form compilations of these formats. The first three formats will usually be in paper or film form (hard copy). This data format is suitable for most information purposes, as a source for updating obsolete figures or maps, or as data to be used in the absence of an expensive GIS (Butler *et al*, 1987; Cordell and Nolte, 1988a). However, in this form it is unsuited to modern GIS, which requires that all data be digitally encoded.

The main sources of secondary data may be classified as per Table 3.2. This list is not exhaustive and sub-categorization is possible in all main categories. The source list was compiled largely from : Goddard (1983); FAO (1985); Alonzo (1988); Cordell and Nolte (1988b) and Turnbull (1989). Most of the sources in Table 3.2 are straightforward and may be familiar. They have been listed in several categories in order of increasing utility to the spatial analyst, though in some categories, e.g. handbooks and manuals, it might depend on the particular handbooks or manuals.

There are several trends in evidence regarding secondary data sources. With the advent of new electronic "on-line" methodologies, searching for secondary sources has been made far easier, as long as access is possible!. Computerized data bases are becoming the norm in university and other larger libraries as well as in national and international organizations and larger government departments. These frequently give instant access to files containing abstracts or references on particular subject areas which have been requested.

There has also been an almost exponential proliferation in both academic and trade journals over the past two or three decades as well as a proliferation of specialized conferences which have spawned their "proceedings". It is this secondary "data surge" which has led first to the need for abstract and bibliographies, then for microfiche facilities and more recently for computer data bases. There has also been a growing "internationalization" of data, a precedence for the English language and a move towards more and more subject specialization.

Table 3.2 Major Sources of Secondary Information on Aquaculture and Inland Fisheries

Reference Source	Degree of Utility
Dictionaries and Glossaries	L
Encyclopaedias	L
Annuals and Yearbooks	L
Newsletters	L
Audio Visual sources	L
Annual and Quarterly Reports of Fish Depts.	M
Directories	M
Textbooks	M
Catalogues	M
Trade journals or magazines	M
Handbooks and Manuals	M
Censuses	M
Atlases and Gazetteers	M
Reports and Conference Proceedings	H
Bibliographies	H
Primary journals	H
Abstracts	H
Statistical sources	H
Remote Sensing sources	H
Maps	H
Computerized Databases	H

L = of little use. M = of medium use. H = highly useful.

There are several major problems with secondary data acquisition which should be commented on. We have alluded to the difficulty still of gaining access to on-line data base facilities - this remains difficult for many unless fairly high charges can be met or unless access is available via specific occupations. Secondly, much of the secondary data which is of value to those seeking to optimize spatial locations, does not unfortunately fit into easily classifiable categories - we noted earlier how aquaculture and inland fisheries intruded into a complex variety of subject fields. Thirdly, maps are an obvious source of location data, yet map classification is still a poorly ordered subject area. There are many confidentiality and copyright problems to data acquisition which are only slowly being overcome, as are the problems of locating and accessing digital spatial data sets and archives (Dept.of Environment, 1987; Finch and Rhind, 1987).

3.3.2 The Application of Secondary Data to Delineating Production Function Variability

It would be possible to obtain all data necessary to determine production function variability (of all functions) using only primary data collection. However, since aquaculture and inland fisheries now usually operate in a production environment which incorporates a wide spatial area, this is totally impractical. It would also be possible to obtain most of the necessary data using secondary sources. Here we will restrict our comments to those production functions whose data sources are almost entirely secondary, and we will not be looking at maps as a data source (see section 3.3.3).

Data on market accessibility would be derived from not only maps, but also from various trade and business directories. Sometimes there is government documentation (from Fishery Depts.) giving fish outlets, and in some countries there are wholesale or retail trading associations who issue bulletins or trade magazines. As well as using these sources to seek national information on fish wholesalers, retailers, large institutions, catering chains or outlets, supermarkets, fish freezing or other processing plants, it may be worth seeking data on export opportunities or, at the other extreme, data from various "Chambers of Trade" or directories covering local areas.

Since factors relating to climate must cover as long a temporal period as possible, clearly this data will only be available in published sources. These might comprise, at a general level, larger scale atlas maps but preferably more specific data should be acquired from meteorological offices, agricultural departments or other government sources. River water quantity data is also best obtained from where long-term flow measurement records are kept - these too would usually be government sources or, more specifically, water supply or river authorities.

The availability of inputs which might be obtained from a distant source is clearly going to require secondary data - usually from trade or business directories, from specialist fishery or aquaculture magazines or from the extension services. A good general source of secondary data in many countries is the government organization responsible for overall planning and policy. Of necessity this organization collects and collates statistics on all sectors of the economy, including production from agriculture and livestock by year and by administrative unit. Even if all of the desired data are not available from this unit, the personnel can often direct one to possible sources.

It will be a decision for the intending fish producer, or fishery planner, to determine the balance between obtaining the necessary information from primary or secondary sources. It would be unwise to rely on just one or the other - the balance will largely depend on the resources available for site selection, the amount of secondary data which is actually available and the amount of knowledge which the intending entrepreneur or government official has about the importance of the location decision.

3.3.3 Sources of Maps as a Secondary Data Source

Existing maps will undoubtedly prove to be the best source of data for examining the distribution of most production functions. As Butler *et al* (1987) has stated, maps "....provide accurate, clear and unambiguous information about the occurrence of various phenomena on or near the surface of the earth." (p.1). A map is "....a carefully designed instrument that records, analyses and displays the inter-related factors of the area in their true relationship to each other." and "In many decision-making processes the truly useful information is often that which is obtained from studying the overall relationship of all the data." (p.1). Butler later explains the essential part that maps and the mapping services can play in the development process generally - this includes many aspects which are directly relevant to both aquaculture and inland fisheries. Butler is a useful source on all aspects relative to the methodology of mapping.

Before we look at uses of the various types of maps (in Chapter 5), we will review here some major sources from where maps can be obtained. The spatial coverage on these sources will be limited and may show a European bias.

There are several sources which give detailed information on the availability of maps throughout the world, e.g. Muriel (1976), Winch (1976), United Nations (1983), Wolter (1985) and Parry and Perkins (1987). Additionally, the "GeoCenter Internationales Landkartenhaus" issue a hierarchy of publications which can be obtained from:

Postfach 800830, D.7000 Stuttgart 80, West Germany.

Nearly all countries have their own national mapping bodies, most of whom produce topographic and other thematic maps and who issue regular notifications of their publications. Table 3.3 gives a selected list of national mapping organizations (from Lawrence, 1983), and Table 3.4 illustrates the range of map data products available through the National Cartographic Information Center in the U.S.A. (after Cordell and Nolte, 1988b)

Table 3.3 Selected List of National Mapping Organizations

AUSTRALIA	Division of National Mapping Department of Minerals and Energy, Canberra
AUSTRIA	Bundesamt für Eich-und-Vermessungswesen, Vienna
BELGIUM	Institut Géographique Militaire, Brussels
CANADA	Department of Energy,Mines and Resources, Ottawa
EIRE	Ordnance Survey, Dublin
FRANCE	Institut Géographique National, Paris
GERMANY	Institut für Angewandt Geodesie, Frankfurt
ITALY	Instituto Geografico Militare, Florence
JAPAN	Geographical Survey Institute, Ministry of Construction, Tokyo
NETHERLANDS	Topografische Dienst, Delft
NEW ZEALAND	Lands and Survey Department, Wellington
PORTUGAL	Instituto Geografico e Cadastral, Lisbon
POLAND	Glówny Urzad Geodezii Kartografii, Warsaw
SPAIN	Servicio Geografico del Ejercito, Madrid
SOUTH AFRICA	Trigonometrical Survey Office, Pretoria
SWITZERLAND	Eidgenössische Topographische, Berne
UNITED KINGDOM	Ordnance Survey, Southampton
U.S.A.	United States Geological Survey, Reston, Virginia

Table 3.4 Map Data Products Available Through the National Cartographic Information Center

a) U.S. Geological Survey (USGS) topographic and thematic maps.
b) Color separates (from topographic maps).
c) Feature separates (from topographic maps).
d) Out-of-print map reproductions.
e) Land-use, land cover and associated maps.
f) Slope maps.
g) Digital terrain maps.
h) Maps on microfilm.
i) Orthophoto quads.
j) Geographic computer searches.
k) Geodetic control data.
l) Reproductions on microfiche of State place names.
m) County maps.
n) Topographic maps on rolls of 35mm microfilm.
o) Autopositives.
p) Geographic coordinates of various U.S. and selected world names.

There are also many private and commercial firms who publish high quality maps, e.g. Bartholomews, Geographica, Philip's, Michelin, Oxford University Press, Rand McNally, Denoyet-Geppert, Hallwag. These firms and others usually supply detailed catalogues. Many national, state or local government departments produce detailed (usually thematic) maps, e.g. Environmental, Agricultural, Industrial, Conservation Departments, etc., and local planning authorities are frequently obliged to provide mapped details of existing and future, urban and rural, plans at various scales.

Various international and national map libraries exist with possibly the most extensive collection being held by the British Library in London (about 1 450 000 sheets plus >20 000 atlases). The British Library has recently instigated "CARTO-NET" - a fully functioning, automated map cataloguing and retrieval system which gives a complete bibliographic cover of all maps and map series, based on either a grid coordinate search or by interactive graphics (Morris, 1987).

There are now many government, commercial and academic bodies who are creating digitized topographic and thematic maps, and who are creating archives of their materials. Several developed countries have set targets to have completed digital mapping at 1:50 000 scale or larger by the end of this decade. Various global scale data sets are available, e.g. World Data Bank 1 and 2, and Bickmore (1987) reports a topographic data base for the environmental sciences containing contours, river networks and coastlines, digitized from 1:1 000 000 scale maps. The FAO also holds many continental or world scale digitized maps. Openshaw *et al* (1986) and Maling (1989) report the application of the interactive video disc for the storage of large numbers of maps in a computer accessible form which does not overwhelm the electronic storage capacity. These maps do not need to be digitized but at the moment they suffer from poor resolution. Several other marine and river data base sets are available, e.g. the MARIS system for the Atlantic coastline of Canada (Butler *et al*, 1986), and the National River authorities data bases of some river systems in England and Wales. These localized data bases have limited availability and accessibility. Digital mapping will receive further coverage in Chapter 6.

Other map and mapping sources include various atlases, thematic atlases, cartographic journals, university geography departments, gazetteers, map and atlas collections, etc., many of which are documented in Lawrence (1983).

3.4 "Proxy" Data Sources

Although unlimited primary data could be collected and much secondary data exists, there will inevitably be deficiencies in relevant data coverage, for some functions in some areas, which could most efficiently be filled by using "proxy" data. This would be data which had been collected and which might appear to have little or no relevance to aquaculture or inland fisheries. The analyst or entrepreneur would need to decide that, on balance, given the time and cost effort needed to collect the true data, it would be more cost-effective to use this alternative. The data itself might be in any of the formats suggested in section 3.3.1. Table 3.5 exemplifies possible "proxy" data which might be used for the particular functions as specified. Any "proxy" data would need to be used with care - clearly some sources are more relevant than others and the degree of relevance would vary spatially. In many cases the balance between using "proxy" data and collecting the relevant primary data might depend upon the accuracy of the "proxy" data or the scale at which it was mapped.

Table 3.5 Examples of Possible Uses of "Proxy" Data

Production Function Requiring Data	Possible "Proxy" Data
1) Soil quality	The distribution of particular plant species.
2) Water quality	The distribution of various aquatic fauna and flora, or the kinds and amounts of various types of land use.
3) Water temperatures	Maps or tables of air temperatures.
4) Catering outlets	Directories listing hotels or restaurants.
5) Underground water sources	Hydrogeological or geology maps.
6) River water quantity	Annual rainfall maps.
7) Land costs	Population density maps.
8) Wholesale market outlets	Distribution of large towns and cities.
9) Fertilizer inputs	Livestock and/or poultry farms.
10) Availability of capital inputs	Distribution of large towns and cities.

Occasionally, where sufficient statistical data exists, it is possible to show a suspected relationship between two variables by the use of scattergrams, regression analysis or correlation coefficients, e.g. there is often a relationship between altitude and rainfall. If this relationship is proven to be strong, then the use of an altitude or relief map of the area covered by the data could be used as a "proxy" data source for rainfall. However, since there is certainly not a universal relationship between altitude and rainfall, then the use of this method for establishing "proxy" data would be spatially limited (unfortunately to an unspecified degree). Sometimes it might be relevant to use two or more "proxy" data sources, e.g. "land costs" could be a function of population density and "quality of land". Most of the "derived" maps, which will be exemplified in Chapter 5, incorporate one or two sources of "proxy" data.

CHAPTER 4 - REMOTE SENSING AS A DATA SOURCE

4.1 Introduction

Much of what has been discussed in Chapter 3 could be said to have little significance to most of the world. Primary and secondary data collection is, in many senses, an expensive luxury - something which is only realistically applied to those small portions of the earth's surface which are characterized by being comparatively densely populated and which have a high G.N.P. per capita. The vast majority of the world is not like this. There are no structures or means to plan and carry out questionnaire surveys, to equip and organize time series evaluations for several parameters of water quality, temperature or quantity, or to differentiate between the relative accessibility of differing production inputs. Life is not organized at this scale. There has never been the need to gather and collate the type of information which would be of use to intending fish producers, or indeed to almost any entrepreneur.

However, this is changing. In Chapter 1 we outlined the crucial need to select and reserve land or water areas which would be suitable for aquaculture or inland fisheries, i.e. in order to best increase food supplies, employment opportunities and to increase the wealth of an area. Whilst it is beyond the means for most developing countries to intensively survey their territories for a large number of varied parameters using ground based techniques, this is quite within the means of remote sensing (RS) technologies. In this chapter we aim to first look at RS by examining its definition, its development and its methods, and then to examine how RS can be of value to aquaculture and inland fisheries. We shall also need to acknowledge that, although RS has brought many benefits to the spatial analyst, there are still many limitations with regard to its use. Because there are several recent FAO publications which provide background information on RS (Lantieri, 1988; FAO-RSC Series 47, 1988; FAO-RSC Series 49, 1989), we shall try to concentrate on its applications to the search for optimizing locations. We shall consider the integration of RS into GIS in Chapter 6, and a number of our case studies (in Chapter 7) specifically consider applications of RS to aquaculture, inland fisheries or related fields.

4.2 The Development of Remote Sensing

Remote sensing is "....concerned with the collection of data by a sensing device not in contact with the object being sensed, and the evaluation of the collected data, which is then termed information and is presented in map form or as statistics." (Howard, 1985). Clearly, the concept of RS covers a huge field - a field within science and technology which encompasses a vast "applications domain", i.e. in the sense of inputs of applied science, applications in the processing field and in the sense of the ways in which RS outputs can be applied.

Since Butler *et al* (1988) have already outlined the historical growth of RS (for the FAO), we will confine our resumé of its development to a few key advances. The human eye is a remote sensor and, although we can capture images which may be stored in the brain and later retrieved, we can only reproduce them in a subjective sense. The eye can only capture visible radiation which occupies a very small part of the complete range of radiation (which is known as the electromagnetic spectrum). To overcome these deficiencies various instruments or systems have been invented and developed. We will be concerned here with those instruments or systems which capture data from an aerial perspective, i.e. allowing maps to be easily created.

As a means of capturing images, the camera was first developed in France in the 1830s, but it was not until 1858 that the first aerial photograph was taken from a captive balloon near Paris. During the rest of the 19th century advances were made in cameras and additional camera platforms were experimented with. The first photograph from an aeroplane was taken in 1909 over Centocelli in Italy. During the first World War aerial photography was utilized on a large and systematic scale, both in Europe and the Near East, with specially designed cameras and film processing techniques being developed. It was during this period that photo interpretation became a recognized field of expertise.

Civilian use of vertical aerial photography greatly improved during the 1920s and 1930s because of advances in both photographic methods and in the aeroplane as a platform. Aerial photography was used in the compilation of topographic maps, by geologists, foresters and planners, mainly in north America and Europe but occasionally to acquire information from more remote areas which might otherwise be unobtainable. During World War II further developments occurred, e.g.:

i) The water penetration capability of aerial film was recognized which meant that bathymetric data could be acquired.
ii) Colour infrared film was developed for camouflage detection.
iii) Advances in radar technology permitted the development of smaller transmitting and receiving equipment, appropriate for airborne use.
iv) A large area of the Pacific war zone was photographically mapped.

During the 1940s and 1950s large-scale, complete country coverages were undertaken using black and white panchromatic aerial photography, i.e. for many of the colonial countries, especially in Africa. By the 1960s aerial photography had been operative long enough to allow for the study of spatial/temporal variations in the environment.

The period from the late 1950s has been extremely active for RS, with developments in the whole applications field occurring at an exponential rate. With satellite launches occurring regularly, following SPUTNIK 1 in 1957, the interest in RS concentrated on the use of this new and unique platform. In 1959 the first earth images were transmitted from EXPLORER 6 and the first meteorological satellite, TIROS-1, was launched in 1960. The next major advance for RS occurred with the launch of the Earth Resources Technology Satellite (ERTS-1, later renamed Landsat 1) in 1972. This was the first satellite designed to provide long-term, uniform global coverage, having the ability to transmit data gathered on a variety of instruments, for eventual mapping at scales of 1:250 000 to 1:1 000 000. Since Landsat 1 there has been a succession of earth monitoring satellites launched, first by the U.S.A. and the U.S.S.R., but more recently by other countries. Their equipment has become progressively more sophisticated allowing a greater range of imaged data to be interpreted at a more detailed spatial resolution (Travaglia, 1989).

As both Howard (1985) and Butler *et al* (1988) make clear, we should not let the blossoming satellite technologies mask the fact that airborne RS is still thriving and vital. Aircraft have a number of distinct advantages over satellites, mainly in terms of their flexibility of altitude, scheduling and payload. They do not have the same cloud cover problems that satellites have and they can provide low cost, excellent images of smaller areas. Howard (1985) estimates that airborne techniques, using colour infrared technology at high altitude, can allow more than 20 000 km^2 to be photographed, and be thematically mapped at a scale of 1:25 000 to 1:100 000, each day.

It is the rapid surge in the electronics industry which has permitted the post 1960s boom in RS, i.e. because as well as providing for actual developments in data capture, data transmission, image processing, etc., it has spawned the computer technology advances which have been vital to all aspects of space science and have allowed the huge data streams to be efficiently handled. This surge in RS has also been aided by the influx of new ideas from a variety of related disciplines, by the availability of funding for space related activities and by the access to an increasing range of software and hardware. RS has a number of positive advantages over other sensing systems:

i) It allows change to be monitored in a systematic and orderly way.
ii) It is efficient and very cost-effective in per km^2 terms.
iii) It overcomes many data collection problems, e.g. in isolated areas and the fact that normal data collection may terminate at political boundaries.
iv) It can provide for instantaneous updating of information.

Jackson and Mason (1986) report that modern RS has now successfully overcome the problems which it had in the 1960s and 1970s of being "technology pushed". As useful applications of RS imagery have been developed, especially in the fields of food production and environmental awareness, RS is now also being "user pulled". This recent trend has been greatly helped by the growing ability to successfully integrate remotely sensed data into GIS - in fact, we would suggest that if it was not for the functionality offered by GIS, then the future for RS might be rather uncertain (see also Ehlers *et al*, 1989).

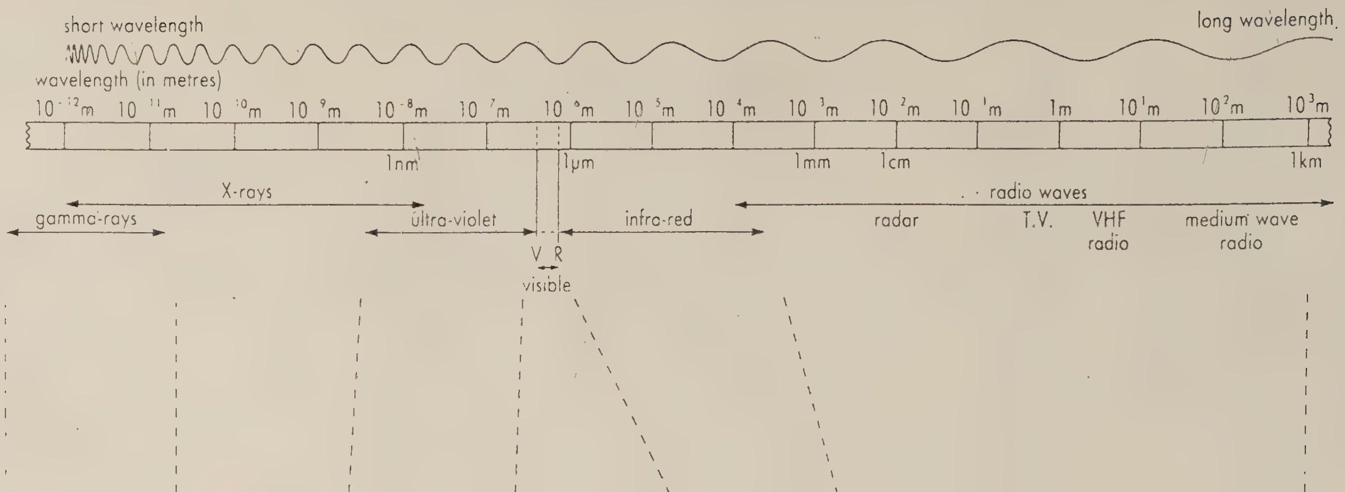
4.3 Electromagnetic Radiation - The Basis of Remote Sensing

"The aim of environmental remote sensing is to utilize sensors, which are mounted on aerial platforms, to identify and/or measure parameters of an object according to variations in the electromagnetic radiation (EMR) emitted by, or reflected from the object." Contained within this statement are a number of concepts which will receive individual attention in the next three sections, in an attempt to clarify necessary RS principles. The interested reader should consult the FAO sources quoted in section 4.1 for further details.

Although we cannot see light (or sound) travelling, we know that it does so. This travel involves the transfer of energy through space or matter in the form of wave motions. The waves that make up EMR travel at a constant speed of 300 million meters per second. All objects reflect and radiate EMR. The amount of electromagnetic energy emitted is a function of the object's temperature - as temperatures increase, the intensity of the radiation emitted increases. There are a whole family of waves which collectively are called electromagnetic vibrations and which vary in their wavelength, and hence (since their speed is constant in space) their frequency. This family may be displayed as a spectrum of energies, hierarchically arranged by wave frequency or wave length (Figure 4.1). The spectrum covers a vast continuum of wavelengths as indicated, and it is usual to rather arbitrarily differentiate between the major wave bands based on certain properties such as their source, method of generation, means of detection, selected applications, etc. Only specific wavelength bands are of interest to RS, i.e. those forming the "windows of transmission", because at these wavelengths filtering out of EMR by the atmosphere is at a minimum. These bands can be shown as in Table 4.1.

The energy which is sensed by the different RS systems is a function of various parameters which might affect the energy before it is received by the sensors. This is shown in Figure 4.2 which indicates that EMR can be natural, either reflected light and other radiations from the sun (Source 1) or emitted heat from the earth (Source 2), or it can be man-made such as from a power station or a radar system. The amount and type of radiation emitted or reflected depends upon incident energy (mainly from incoming solar radiation), the nature of the earth's surface and on the interaction with the earth's atmosphere.

Figure 4.1 The Electromagnetic Spectrum


short wavelength
long wavelength
wavelength (in metres)
10⁻¹²m
10⁻¹¹m
10⁻¹⁰m
10⁻⁹m
10⁻⁸m
10⁻⁷m
10⁻⁶m
10⁻⁵m
10⁻⁴m
10⁻³m
10⁻²m
10⁻¹m
1m
10¹m
10²m
10³m
1nm
1μm
1mm
1cm
1km
X-rays
gamma-rays
ultra-violet
infra-red
V R
visible
radio waves
radar
T.V.
VHF radio
medium wave radio

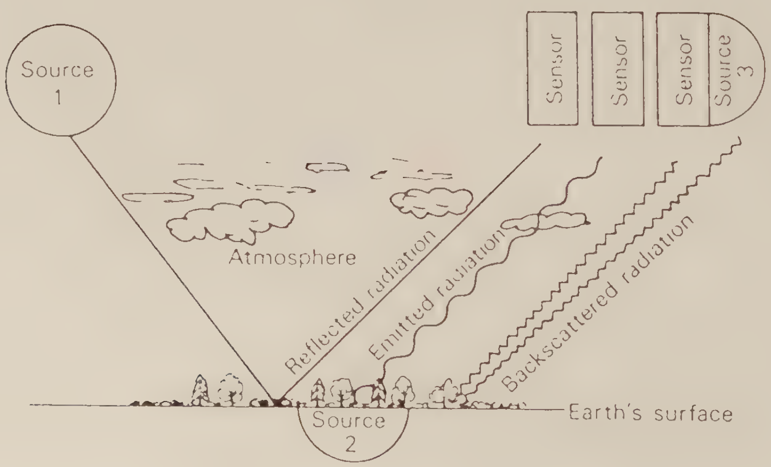
γ-rays	X-rays	U-V	visible	I-R	Radio
Typical wavelength: 10^{-12}m (a million-millionth of a metre)	Typical wavelength: 10^{-10}m (a ten-thousand-millionth of a metre)	Typical wavelength: 10^{-8}m (a hundred-millionth of a metre)	Typical wavelength: 5×10^{-7}m (a two-millionth of a metre)	Typical wavelength: 10^{-5}m (a hundred-thousandth of a metre)	Typical wavelength: 10^{-3}m to 10^{3}m (1mm to 1km)
Sources Radioactive substances like Uranium	Sources X-ray tubes	Sources Very hot objects, Sun, sparks, mercury lamps	Sources Hot objects, Sun, fluorescent substances	Sources Warm or hot objects, Sun	Sources Radio transmitters (including radar and television transmitters) Microwave ovens
Detector Geiger-Muller tube	Detector Photographic film	Detectors Photographic film, causes suntan, fluorescent substances glow	Detectors Eyes, photographic film, photo-electric cell	Detectors Skin, blackened thermometers, photo-transistor	Detectors Aerial and TV set or radio set

The full electromagnetic spectrum is shown below, with the wavelength range marked in. The sources and detectors for each part are also shown.

Table 4.1 Wave Bands of the EMR Spectrum of Interest to Remote Sensing

Wave Band and Wave Length	Detectors	Some Characteristics
Visible 0.4 - 0.7 um	Black & white plus colour photography. T.V. camera. Optical scanner.	High atmospheric scattering effect. Most EMR is reflected solar radiation therefore only used in daylight. Penetrates water.
Near Infrared 0.7 - 3.0 um	Infrared scanner. Infrared thermography. Multi-spectral scanner. Photography. Optical scanner.	High reflectance of vegetation. Again solar energy reflected by surfaces.
Medium Infrared 3.0 - 8.0 um	as above.	as above.
Thermal 8.0 - 1000 um	Radar. Side Looking Airborne Radar (SLAR). Optical scanner.	Predominantly radiation emitted by the earth and atmosphere. Does not penetrate clouds.
Microwave 1 mm - 100 cm	Radar. SLAR. Scanning radiometer.	Can penetrate clouds. Imagery acquired in active or passive mode - daytime or night-time.

Figure 4.2 The Key Features of the Remote Sensing Data Collection Process (after Curran, 1985)


Source 1
Sensor
Sensor
Sensor
Source 3
Atmosphere
Reflected radiation
Emitted radiation
Backscattered radiation
Earth's surface
Source 2

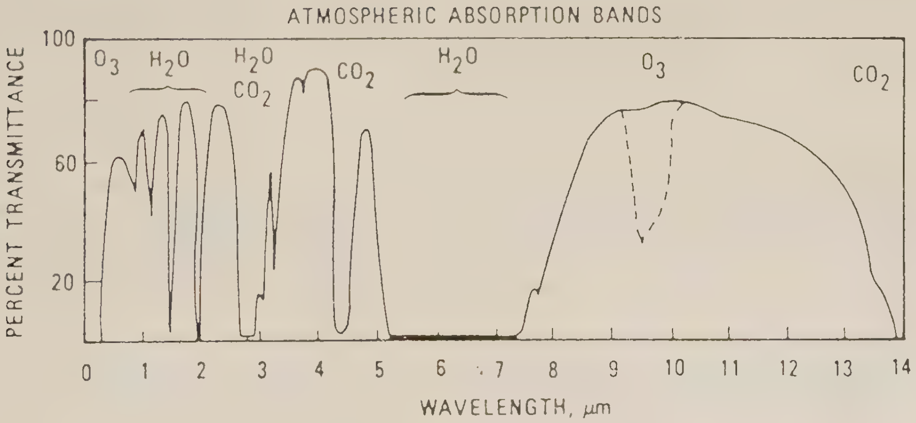
4.3.1 Incident Energy

This comes mainly from the sun and, in the range of the visible and near infrared part of the spectrum, it is the proportion of the incident energy reflected by the "object" on the ground. When the energy sensed is in the range of thermal radiation it comes mainly from the emission of the "object" on the ground, which is itself a function of the sun's incident energy which has been absorbed by that object and then re-emitted as thermal radiation. Incident energy from the sun will vary with season or latitude (affecting the angle of the sun), with the length of time the sun has been shining and with the angle of the object on the ground. When analyzing remotely sensed data it is important to consider dates, time of acquisition and relief.

4.3.2 Effects of Atmosphere

The atmosphere can affect the amount of radiation received by the sensor because the atmosphere itself is heterogeneous, being made up of many gases as well as having dust particles and other pollutants. The atmosphere may scatter light in the visible band and absorb it in the ultraviolet and infrared bands. About 18% of the incident radiation in the atmosphere is absorbed or scattered and about 35% of the incoming solar energy is reflected by the earth and the atmosphere, including clouds. Scattering is caused by particles in the atmosphere reflecting the energy, and the intensity of the scattered EMR depends on the ratio of the wavelength to the size of the particles. Scattering caused by small particles is selective relative to the wavelength, affecting shorter wavelengths more; scattering related to large particles is non-selective, affecting all wavelengths. Because of scattering, the energy received by the sensor includes reflections from the atmosphere as well as from the target (object). Complex algorithms are needed to correct this effect. Atmospheric absorption reduces the amount of EMR reaching the sensor in some wavelength bands. Figure 4.3 shows the percentage of EMR which can pass through the atmosphere as a function of wavelength (revealing the atmospheric windows), and the gases responsible for absorption are noted. Microwave radiations are unaffected by atmospheric conditions, which makes them very useful, especially in cloudy areas such as the tropics.

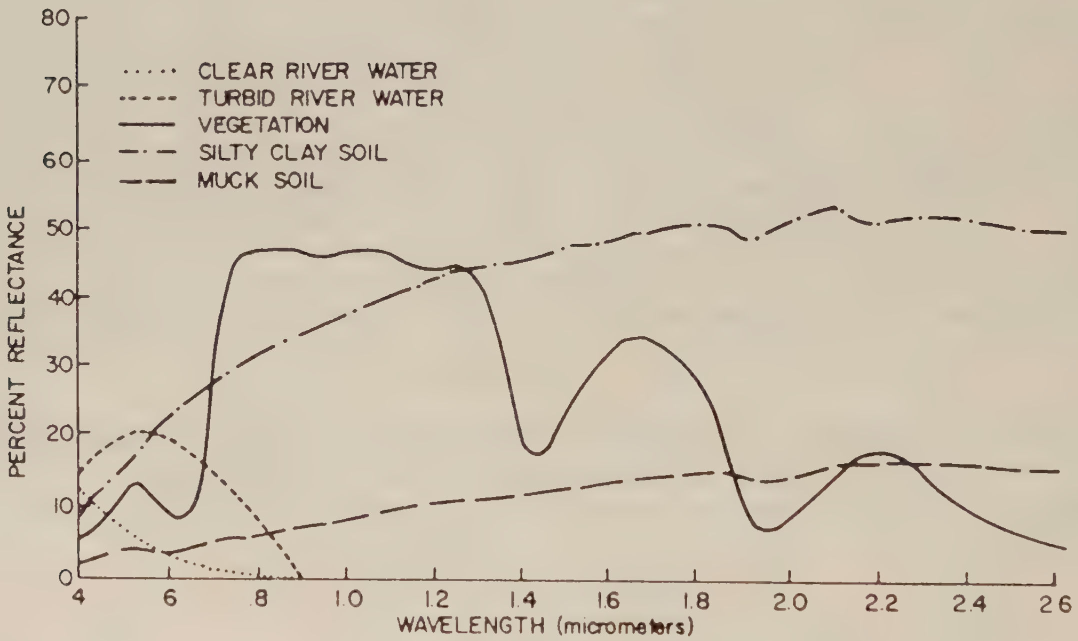
Figure 4.3 Percentage of EMR Able to Pass Through the Atmosphere as a Function of Wavelength (after Sabins, 1978)



4.3.3 Ground Influences

The element of the earth's surface which is in the field of view of the sensor (the target or object) will produce, by reflection or emission, the EMR measured by the RS sensor. The amount of energy transmitted or reflected depends on what the target consists of and the thickness of it. A target also absorbs radiation and this can affect the temperature of the target and thus the amount of energy radiated per second. So all targets (or objects) in the environment emit and reflect different intensities and types of EMR in different portions of the spectrum, i.e. they have a so-called spectral signature which is predictable and repeatable. Figure 4.4 gives the spectral signature of various natural features. These signature curves are dependent on a number of interactions between incoming radiation and the micro and macro-structure of the matter irradiated. Spectral signatures may vary temporally, e.g. as plants grow, or spatially with different types of vegetation, different soil conditions, water availability, effect of topography, etc.

Figure 4.4 Spectral Signature of Various Natural Surface Features



4.4 Remote Sensors

Sensors are the devices used to gather EMR. They will typically consist of four components, i.e. collectors, detectors, signal processors and recording units. There are several ways of classifying sensors - we will describe them under the headings:

a) Framing Systems. These include various types of camera which record instantaneously an entire image.

b) Scanning Systems. These employ a detector (electronic sensor) which sweeps across a scene in a series of parallel lines collecting data in order to record an image. They may employ passive sensors, which record reflected or emitted EMR from natural sources, or active sensors which illuminate an object with their own radiation source, and then record the "echo".

In this section we will be concerned with the sensors theoretically - in Section 4.5. we will consider the actual sensors carried by operational satellites.

4.4.1 Framing Sensor Systems

Cameras may be used from various platforms. We will concentrate here on points significant to satellite photography since airborne photography is well documented in sister FAO publications (Butler *et al*, 1987 and Dainelli, 1988).

The still photography camera is the best known, simplest and cheapest of all sensors, and still photography produces images having a better resolution than those produced by electronic sensors. Cameras may produce simple, single images in one spectral band which are suitable for many referencing purposes, or they can produce overlapping pairs of aerial photographs which, when viewed using a stereoscope, give a three dimensional perspective of the landscape. But their chief use is in multi-spectral photography. Here a number of cameras may take simultaneous images of an object, using several band-pass filters, which each allow EMR information relative to particular wave bands to be recorded. The number, position and width of suitable colour filters can be optimized in a problem oriented manner so that the controller is able to discriminate between a wide range of features (within the visible and infrared bands - in the wavelengths between 0.4 and 1.3 um). The quality of the photographic image will depend on the inter-related factors of: focal length; the angle of view; scale of the photograph; the contrast ratio; the picture resolution and the film speed (Butler *et al*, 1988).

There are a variety of cameras suitable for satellite and/or aerial RS, and their selection depends upon the nature of the application. In principle mapping frame aerial cameras are similar to normal cameras except that they have:

i) Calibrated lenses.
ii) High geometric accuracy.
iii) A medium to large format.
iv) A more complex mechanical and electrical configuration.

Though cameras have the advantages already noted, they do have some disadvantages, i.e. there is a loss of resolution during photo-chemical processing or copying, or in analogue digital conversion for subsequent computer processing, and they have a limited spectral sensitivity. They can also only function in favourable weather conditions.

4.4.2 Framing System Films

Cameras will require different types of film for different purposes. The main types, according to their range of spectral sensitivity, are:

a) Orthochromatic. These have a very good discrimination in the green bands and are used mainly for cartographic reproduction.

b) Panchromatic. These cover the whole of the visible spectrum, with good sensitivity, except for green bands (0.5 um) which can be compensated for with a filter. This film is inexpensive, is easy to process, has a high spatial resolution and special filters can be used to enhance selected objects (targets).

c) Black and White Infrared. This is similar to panchromatic except that its greater spectral sensitivity means that near infrared wavelengths can be recorded in addition to visible light. Usually a dark red filter is used to screen out the visible portion of the spectrum, so that only the near infrared portion is recorded, which results in a greater penetration of the atmosphere. This film is used mainly for detecting different vegetation stages and types, plus the existence of water.

d) Natural Colour. The spectral range of this film is similar to that of panchromatic. It is composed of three layers, each sensitive respectively to the three primary colours - blue, green and red. Colour images offer a range of about 20 000 natural shades whilst black and white is limited to only 200 grey tone shades, i.e. colour film allows the distinguishing of many more features, because of its greater sensitivity to tints and shades. Colour film has a number of applications, e.g. its sensitivity to sub-surface water makes it especially useful for coastline definition and the estimation of water depth and sediment content. However, colour photographs are more expensive, they have a less good image definition and they cannot be taken from a high altitude.

e) False Colour. These films are formed by having three layers sensitive to green, red and near infrared radiations, respectively modulated into blue, green and red. The film has been moderated to achieve several advantages, e.g. a high penetration of the atmosphere, sharp resolution and definition of water bodies and a good response to the infrared reflectivity of healthy vegetation. However, these films have a limited exposure tolerance and the film requires refrigerated storage.

4.4.3 Scanning Sensor Systems

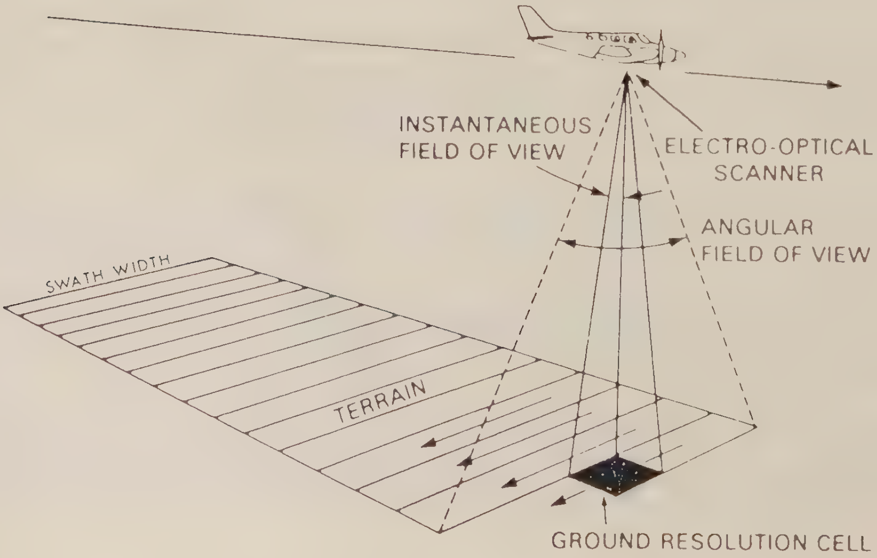
This is the main alternative to photographic systems for detecting and recording EMR. Several bands of the EMR spectrum, either from the ultraviolet to infrared regions (multispectral scanners) or the microwave bands (radiometers), may be scanned simultaneously by optically splitting the collected radiation and diverting each part to a separate detector element. Final image products can be photographs or computer compatible tapes containing digital data. Scanning sensors can be either passive or active. Passive sensors detect natural incoming EMR and active systems detect system-generated EMR (so called "echo").

4.4.3.1 Passive sensors

These sensors are called radiometers and they can detect EMR within the ultraviolet to microwave wavelengths. Two important spatial characteristics of passive sensors are:

i) Their "instantaneous field of view" (IFOV) - this is the angle over which the detector is sensitive to radiation. This will control the picture element (pixel) size which gives the ground (spatial) resolution of the ultimate image (Figure 4.5), i.e. the spatial resolution is a function of the detector angle and the height of the sensor above the ground. For more details on spatial, spectral, radiometric and temporal resolutions see Lechi (1988).

Figure 4.5 The Concept of IFOV and AFOV (after Avery and Berlin, 1985)

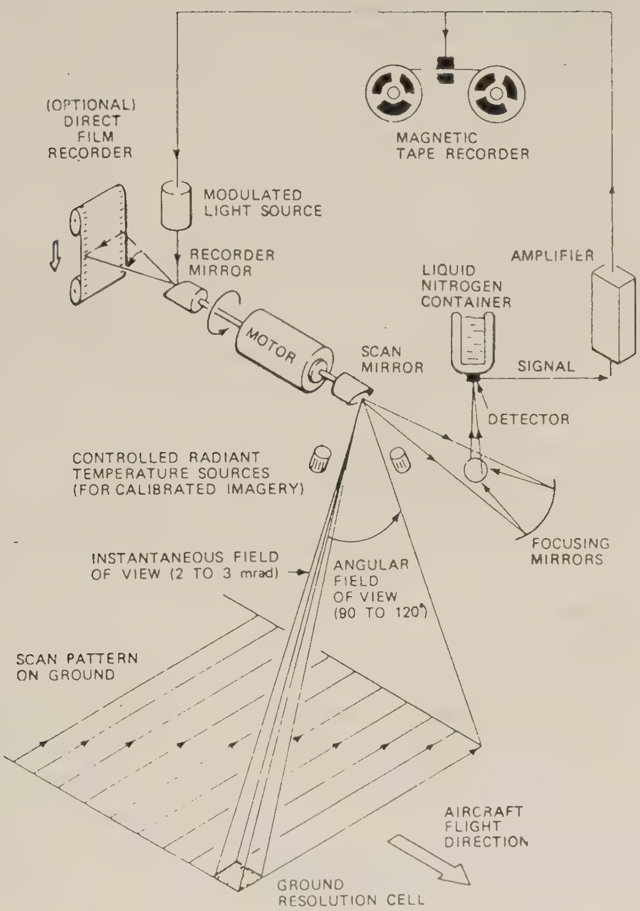


ii) The "swath width" - this is the linear ground distance over which the scanner is tracking (at right angles to the line of flight). It is determined by the angular field of view (AFOV - or scanning angle) of the scanner. The greater the scanning angle, the greater the swath width (Figure 4.5).

There are two main categories of passive sensor:

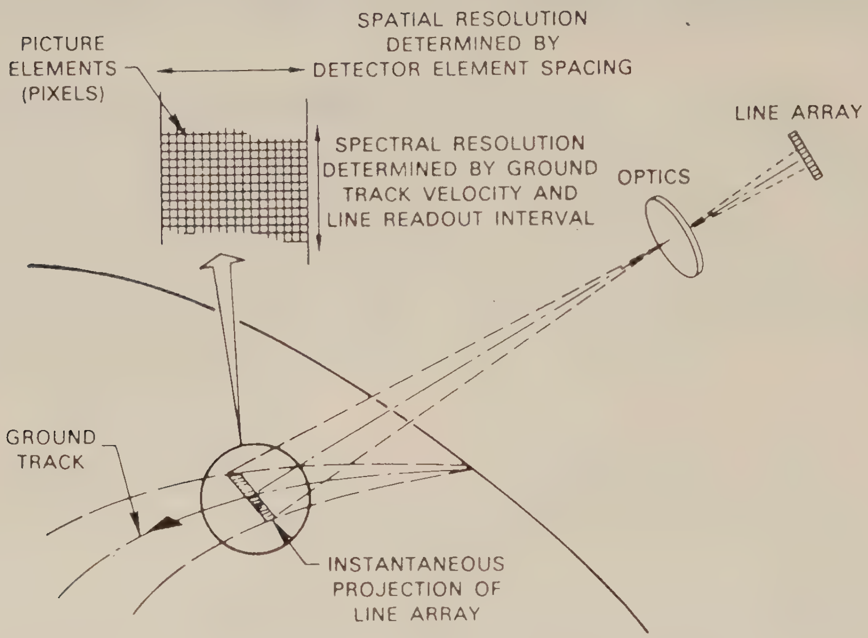
a) A mechanical scanning radiometer. This is an electro-optical imaging system on which an oscillating or rotating mirror directs the incoming radiation onto a detector as a series of scan-lines perpendicular to the line of flight (Figure 4.6). The collected energy on the detector is converted into an electrical signal. This signal is then recorded in a suitably coded digital format, together with additional data for radiometric and geometric calibration and correction, directly on magnetic tape on board the sensor platform.

Figure 4.6 Optical Mechanical Scanning System


(OPTIONAL) DIRECT FILM RECORDER
MAGNETIC TAPE RECORDER
MODULATED LIGHT SOURCE
RECORDER MIRROR
AMPLIFIER
LIQUID NITROGEN CONTAINER
MOTOR
SCAN MIRROR
SIGNAL
DETECTOR
CONTROLLED RADIANT TEMPERATURE SOURCES (FOR CALIBRATED IMAGERY)
FOCUSING MIRRORS
INSTANTANEOUS FIELD OF VIEW (2 TO 3 mrad)
ANGULAR FIELD OF VIEW (90 TO 120°)
SCAN PATTERN ON GROUND
AIRCRAFT FLIGHT DIRECTION
GROUND RESOLUTION CELL

b) A push broom radiometer. This uses a wide angle optical system in which all the scenes across the AFOV are imaged on a detector array at one time, i.e. there is no mechanical movement (Figure 4.7). As the sensor moves along the flight line, successive lines are imaged by the sensor and sampled by a multiflexer for transmission. The push broom system is generally better than the mechanical scanner since there is less noise in the signal, there are no moving parts and it has a high geometrical accuracy.

Figure 4.7 Characteristics of a Push Broom Radiometer (after Avery and Berlin, 1985)

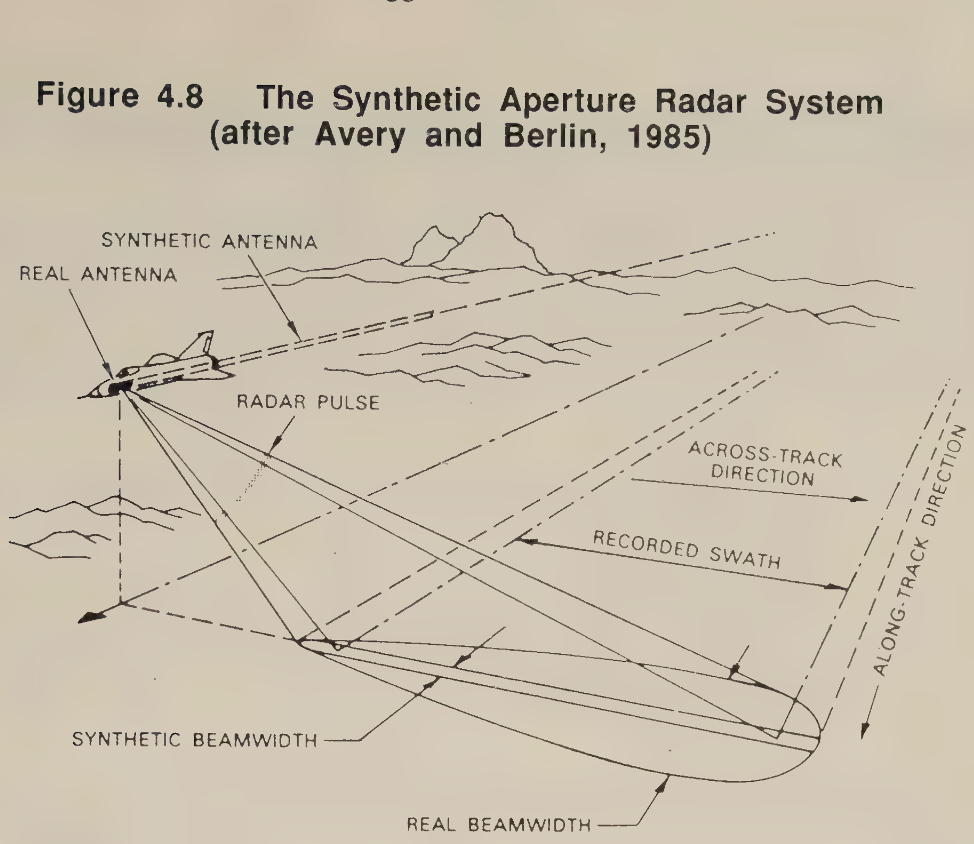

SPATIAL RESOLUTION DETERMINED BY DETECTOR ELEMENT SPACING
PICTURE ELEMENTS (PIXELS)
LINE ARRAY
SPECTRAL RESOLUTION DETERMINED BY GROUND TRACK VELOCITY AND LINE READOUT INTERVAL
OPTICS
GROUND TRACK
INSTANTANEOUS PROJECTION OF LINE ARRAY

4.4.3.2 Active sensors

All active sensors illuminate objects with their own source of radiation. The illumination will either induce an object to emit radiation or cause it to reflect the sensor produced radiation. This ability means that no sunlight is required so imagery can be recorded by day or night or through clouds and light rain. Some active sensor systems are surface-based, e.g. sonar, others could be carried in aircraft, e.g. Side Looking Airborne Radar (SLAR) whilst others can be mounted in satellites, e.g. Synthetic Aperture Radar (SAR). We will review briefly airborne and satellite active systems, which are commonly called Radar, and which are generally classified as either imaging or non-imaging:

a) *Imaging Radars.* These display the radar backscatter characteristics of the earth's surface in the form of a strip map or a picture of a selected area. A type used in aircraft is the SLAR whose sensor scans an area not directly below the aircraft, but at an angle to the vertical, i.e. it looks sideways to record the relative intensity of the reflections so as to produce an image of a narrow strip of terrain. Sequential strips are recorded as the aircraft moves forward allowing a complete image to be built up (Figure 4.8). The SLAR is unsuitable for satellites since, to achieve a useful spatial resolution, it would require a very large antenna. A variant used in satellites is the SAR whose short antenna gives the effect of being several hundred times longer by recording and processing modified data.

Figure 4.8 The Synthetic Aperture Radar System (after Avery and Berlin, 1985)



b) *Non-imaging Radar.* These are also called scatterometers since they measure the scattering properties of the region or object being observed, i.e. the roughness of the surface over a wide swath on either side of the spacecraft. A type of scatterometer is the radar altimeter which can provide an accurate height assessment for satellites, and these measurements can yield valuable topographic or sea surface roughness variations.

A further type of active sensor is the laser radar (LIDAR). LIDARs use lasers to generate short, high power light pulses. These can be used to measure the intensity of light back-scattered by the target as a function of the distance from the sensor. Because of their size LIDARs are presently limited to airborne craft.

4.5 Remote Sensing Platforms and Sensors Being Carried

In this section there will be no need to detail all the various platforms and their sensors since this has been exhaustively studied elsewhere, e.g. with regard to fisheries applications see Cheney and Rabanal (1984), Butler *et al* (1988) and Petterson (1989). Here it will be appropriate to mention some of the platforms commonly used, to explain the two general types of environmental satellite system, to summarize the operational systems presently in use and to exemplify the main sensor types being carried. Since it has received little attention elsewhere we will briefly mention the scope and availability of RS imagery from the U.S.S.R.

4.5.1 Sensor Platforms

Sensors can be carried on space, air, terrestrial or water-borne platforms but it is beyond our remit to examine the latter two types. There are various major airborne or space platforms as follows:

a) *Balloons.* These may be free floating or anchored, and the former can be gas filled, hot air or propelled. They are now infrequently used, because they are slow, although there has been some discussion on bringing back into service the dirigible balloon.

b) *Helicopters.* They may be useful for the essential "ground truthing" work, i.e. collecting statistical data in more remote areas to verify images obtained from higher and faster platforms. They have rarely carried sensors directly.

c) *Space Shuttles or Laboratories.* These are essentially manned space missions. They frequently carry experimental payloads which may require human testing or adjustment, or interactive participation with ground researchers. Any of the previously mentioned sensors can be utilized, and some of them, e.g. photography, with a great deal of flexibility.

d) *Airborne.* There are several sub-categories of this platform, according to flight altitude:

- i) *High altitude aircraft* - these usually operate at over 8 000 meters allowing for photography at about a 1:100 000 scale, or the use of multi-spectral scanners and Radar systems.
- ii) *Medium altitude aircraft* - which operate at 3 000 to 8 000 meters and can take photographs at a 1:20 000 to 1:80 000 scale or carry multi-spectral scanners.
- iii) *Light aircraft* - which fly below 3 000 meters and can do aerial reconnaissance, take large-scale photographs and can supplement missing or uncertain satellite imagery.

e) *Satellites.* Since these are the platforms which provide the bulk of the remotely sensed data, and they are likely to be of increasing importance in the future, we shall examine them in more detail in the next section. There have now been many hundreds of satellite launches, mostly by the U.S.A. and U.S.S.R., and the majority have been for military purposes. Recently several other countries have launched their own satellites, either independently or in joint ventures. Initially, satellites were largely experimental, but they are now increasingly research or operational platforms, with most of them carrying a varied sensor payload. Their primary capability is to carry sensors which can monitor the entire earth surface on a periodic basis, sensing a large area during each revolution. They all operate at an altitude which is sufficient to escape from the earth's atmospheric drag but still remain within the dominant gravitational field, i.e. between 150 kms and 40 000 kms. Most satellites have been launched from rockets, whilst some have been launched aboard a shuttle spacecraft, from where they are unloaded into space. It has been recently demonstrated that the in-flight repair of satellite systems is now viable, though this is unlikely to be cost-effective for unmanned craft.

The advantages of satellites include the repetitive coverage of the earth's surface at various scales and at varying resolutions, with data being acquired on a routine and cost-effective basis. Often satellite-sensed data is the only information available for large tracts of ocean, mountain, desert or tropical forest areas. The disadvantages include their large capital costs, which include permanent monitoring and receiving stations, their relatively poor resolution for many environmental purposes and the fact that cloud cover remains a problem for many sensing devices.

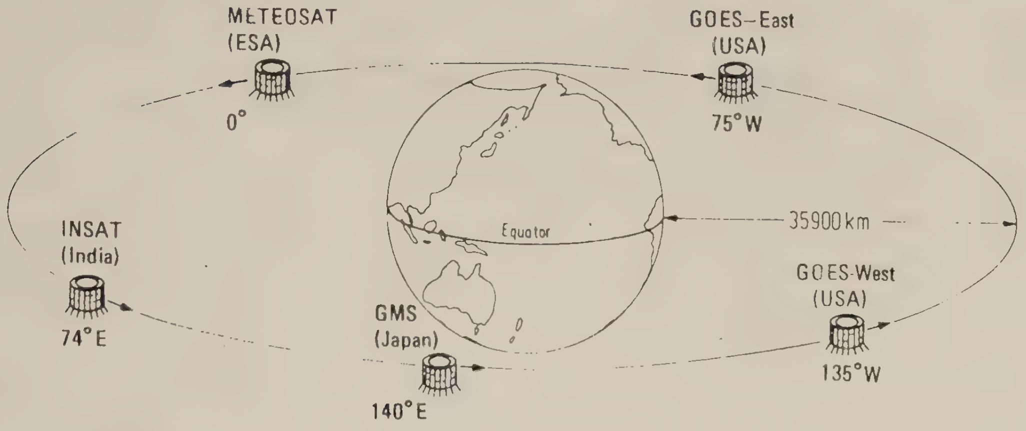
4.5.2 Types of Environmental Satellites

It is convenient to classify environmental RS satellites into two major types, i.e. geostationary and near-polar orbiting.

4.5.2.1 Geostationary satellites

These are satellite sensing systems which are boosted into a high geosynchronous orbit at approximately 35 900 kms above the equator, i.e. at this altitude the speed of the satellite can exactly match the speed of the earth's rotation. Because of this height, they have a limited number of uses, e.g. to transmit telecommunication signals or to get a broad view of the weather. The fact of remaining stationary means that they can achieve a high temporal resolution, but the great height means that spatial resolution is normally only in the range of 2 to 5 kms, according to wavelength. This type of satellite was first launched in 1966 and there are currently five geostationary satellites which each cover a different portion of the earth (Figure 4.9). They can image the earth's surface between latitudes 80N and 80S and they are able to image and transmit data on their whole viewable area every 30 minutes.

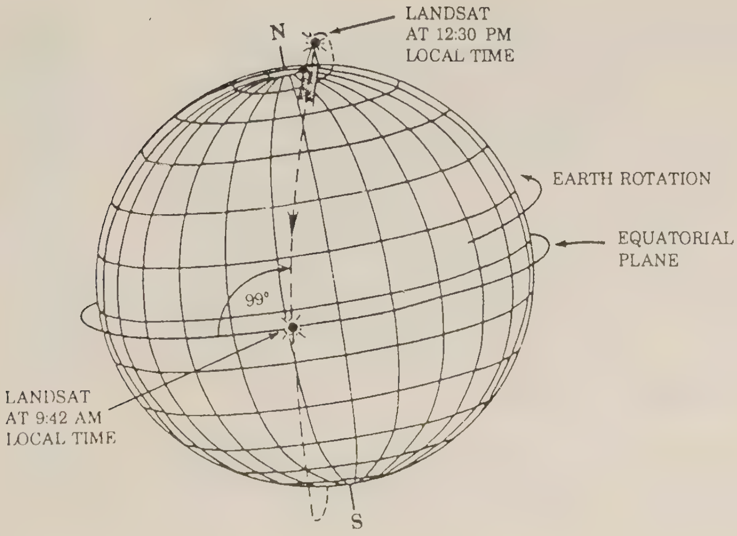
Figure 4.9 Positions and Names of the Five Geosynchronous Satellites Providing Meteorological Data (after Richards, 1986)


METEOSAT
(ESA)
0°
GOES–East
(USA)
75°W
INSAT
(India)
74°E
Equator
35900 km
GOES-West
(USA)
135°W
GMS
(Japan)
140°E

4.5.2.2 Near-polar orbiting satellites

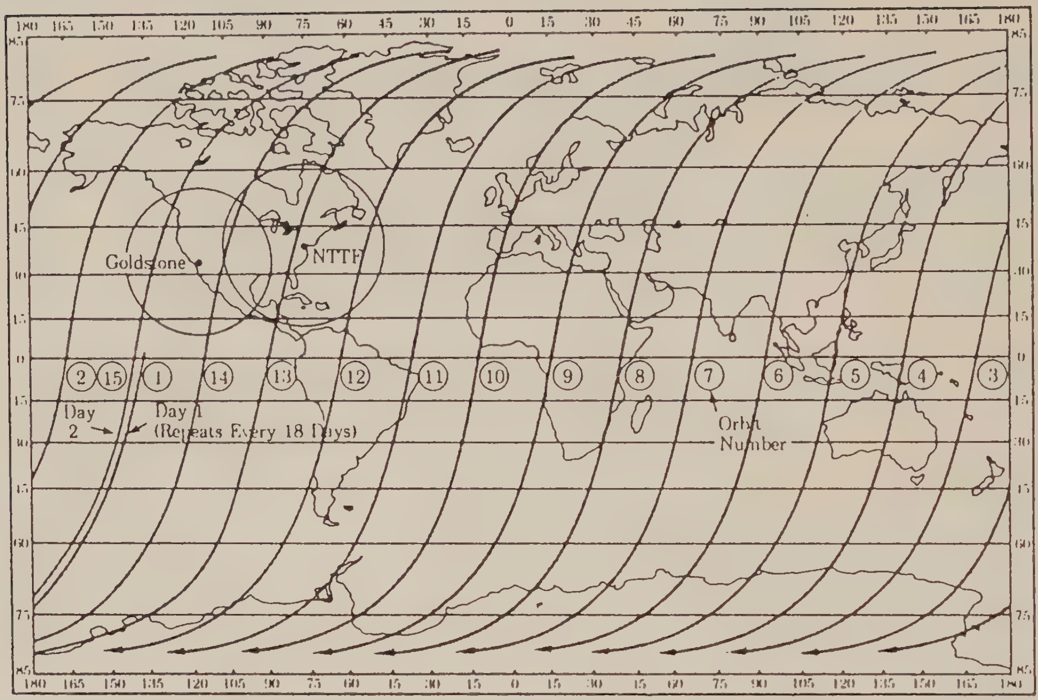
These satellites orbit the earth, with an inclination relative to the equator of nearly 90 degrees, i.e. so that their orbit nearly crosses the north and south poles (Figure 4.10). Their orbit height varies between about 270 kms and 1 600 kms and it is usually sun-synchronous - meaning that it crosses the equator at the same sun time each day. By having this type of orbit, the satellite visits any particular point above the earth at the same time, which is useful for the comparative analysis of multi-temporal data. One complete revolution of the earth takes about 95 to 115 minutes (depending on altitude), meaning that 12 to 16 revolutions are achieved each day. The

Figure 4.10 A Typical Orbital Track for a Polar Orbiting Satellite (after Taranik, 1978)


N
LANDSAT
AT 12:30 PM
LOCAL TIME
EARTH ROTATION
EQUATORIAL
PLANE
99°
LANDSAT
AT 9:42 AM
LOCAL TIME
S

exact inclination of the flight path will determine the time period between re-visits to any specific location, but it is commonly once every 16 to 20 days (Figure 4.11). These satellites have a working life expectancy of about four years.

Figure 4.11 Typical Orbital Track for Each Orbit and for a Repeat Visit (after Taranik, 1978)



4.5.3 The Major Operational Environmental Satellites

A number of environmental RS satellite systems and/or programmes have been in operation since the mid-1960s. Some of these programmes are ongoing, others have ceased. Table 4.2 attempts to list the main programmes. We mention many programmes briefly since a large amount of data has been acquired from them, much of which may still be valid and available. We shall describe here the main characteristics of four satellite systems, i.e. Landsat 4 to 5, SPOT 1, ERS-1, MOS-1 and Kosmos - their sensors will be described in the next section. These are selected because they are either currently providing data or because they are the most recent of the orbiting satellite series. It is difficult to select satellite systems for study which are particularly relevant to aquaculture and inland fisheries, because much of the environmental data gained from any of the systems is potentially useful. Section 4.7 will be concerned with the potential applications of satellite data to location analysis for fish production sites.

4.5.3.1 Landsat 4 and 5

Landsat 4 and 5 were launched respectively in July, 1982 and March, 1984. They both have an angle of inclination of 98.3 degrees and an orbital time of 98.5 minutes. The satellites make 14to 15 revolutions per day and it takes 16 days before a revisit track is made. The Landsat

Table 4.2 The Main Environmental Polar Orbiting Satellite Systems or Programmes

Satellite Programme	Country	Year of 1st Launch	Operational State	Sensors Carried
Tiros/NOAA 1st series.	U.S.A.	1970 - 1976	ceased	AVHRR; AVCS.
Landsat 1,2,3	U.S.A.	1972 - 1978	ceased	MSS; RBV.
Meteor	U.S.S.R.	1977	active	MSS; MRTVK.
Tiros-N/NOAA 2nd series.	U.S.A.	1978	active	AVHRR.
HCMM	U.S.A.	1978	ceased	HCMR.
Nimbus-7	U.S.A.	1978	ceased	CZCS; SMMR; LIMBS.
Seasat-A	U.S.A.	1978	ceased	SMMR; RA; SASS; SAR; VIRR.
Landsat 4,5.	U.S.A.	1982 - 1984	active	MSS; TM.
Kosmos	U.S.S.R.	1983	active	SLAR; MRIR; MRTVK. plus cameras
SPOT-1,2.	France	1986	active	HRV.
IRS-1A	India	1988	active	LISS.
MOS-1a, b	Japan	1987-1990	active	MESSR; MSR; VTIR.
NROSS	U.S.A.	1989	active	Scatterometer
ERS-1	European Space Agency	1990	planned	AMI; SAR; ATSR-M; RA; Scatterometer.
Landsat 6.	U.S.A.	1992	planned	ETM:

AMI	Active microwave instrument.
ATSR-M	Along-Track scanning radiometer.
AVCS	Advanced vidicom camera.
AVHRR	Advanced very high resolution radiometer.
CZCS	Coastal zone colour scanner.
ETM	Enhanced thematic mapper.
HCMR	Heat capacity mapping radiometer.
HRV	High resolution visible instrument.
LIMBS	Profile temperature radiometer.
LISS	Linear imaging self scanning sensor.
MESSR	Multispectral electronic self-scanning radiometer.
MRIR	Medium resolution infrared radiometer.
MRTVK	Multispectral television system.
MSR	Microwave scanning radiometer.
MSS	Multispectral scanner.
RA	Radar altimeter.
RBV	Return beam vidicom system.
SAR	Synthetic aperture radar.
SASS	Seasat satellite scatterometer.
SLAR	Side looking airborne radar.
SMMR	Scanning multichannel microwave radiometer.
TM	Thematic mapper.
VIRR	Visible and infrared radiometer.
VTIR	Visible and thermal infrared radiometer.

Figure 4.12 The Landsat Swathing Pattern and Successive Orbit Paths (after Taranik, 1978)

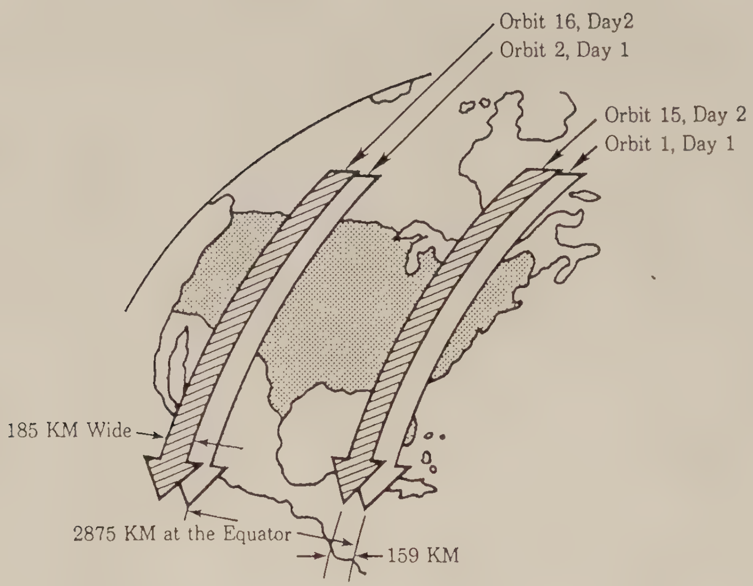
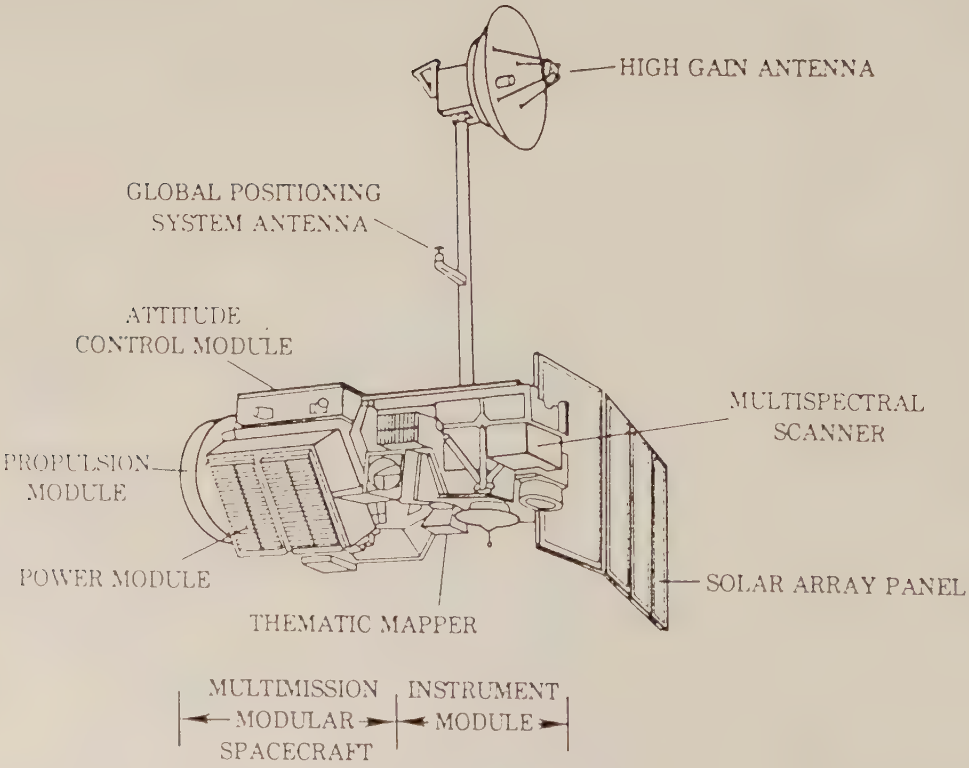

Orbit 16, Day2
Orbit 2, Day 1
Orbit 15, Day 2
Orbit 1, Day 1
185 KM Wide
2875 KM at the Equator
159 KM

Figure 4.13 Configuration of Landsats 4 and 5


HIGH GAIN ANTENNA
GLOBAL POSITIONING SYSTEM ANTENNA
ATTITUDE CONTROL MODULE
MULTISPECTRAL SCANNER
PROPULSION MODULE
POWER MODULE
SOLAR ARRAY PANEL
THEMATIC MAPPER
MULTIMISSION MODULAR SPACECRAFT
INSTRUMENT MODULE

distance between successive orbits. These satellites are a continuation of the original Earth Resources Technology Satellites (ERTS) programme, initiated in 1972, which later developed swathing pattern is illustrated in Figure 4.12, which also shows the width of swath and the into the Landsat series. Landsat 4 and 5 differ from the earlier Landsats by the introduction of the Thematic Mapper sensor and the exclusion of the Return-Beam Vidicom (Figure 4.13).

There are some 18 receiving stations around the world from where Landsat data is transmitted to NASA's Goddard Spaceflight Center. It is then passed to a commercial company (EOSAT) for processing and distribution. Both Landsat 4 and 5 have well outlived their life expectancy yet continue to operate because some of the on-board systems have been closed down to save power. There is likely to be a "data gap" when these two satellites finally cease to transmit, i.e. since lack of funding and technical problems will prevent Landsat 6 from being launched until the second quarter of 1992.

4.5.3.2 SPOT-1

SPOT-1 (Système pour l'Observation de la Terre) was launched in February, 1986. It was constructed by the French in cooperation with Belgium and Sweden. It has a sun-synchronous orbit at an inclination of 98.7 degrees, and a revolution period of 101.4 minutes. It makes 14 or 15 revolutions per day and revisits the same track every 26 days. It's altitude varies from 820 to 840 kms and it can acquire images between 84 degrees North and South. A key feature of SPOT is the provision for off-nadir viewing, i.e. it can "look" sideways for up to 27 degrees from the vertical in either direction, extending the field of view by 475 kms each way. This allows for a much reduced revisit time, although images would then necessarily be from an oblique angle. This off-nadir facility is steerable from ground control (Figure 4.14). Off-nadir viewing also allows for stereoscopic viewing - pairs of images of a given scene can be recorded at different viewing angles during successive satellite passes in the vicinity of the scene concerned (Figure 4.15).

Figure 4.14 SPOT Off-Nadir Revisit Capabilities
(from SPOT Image Newsletter, 1986)

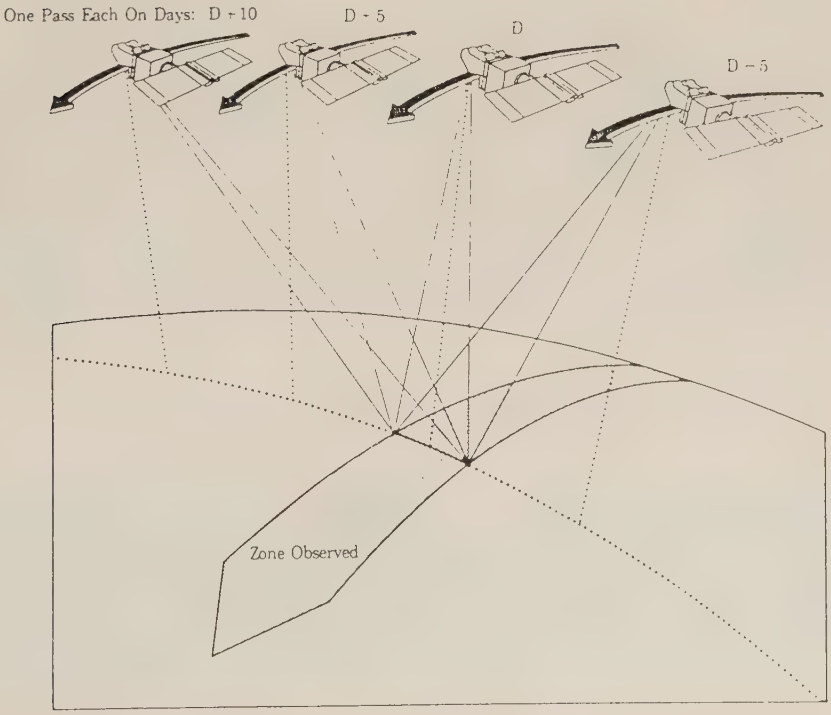
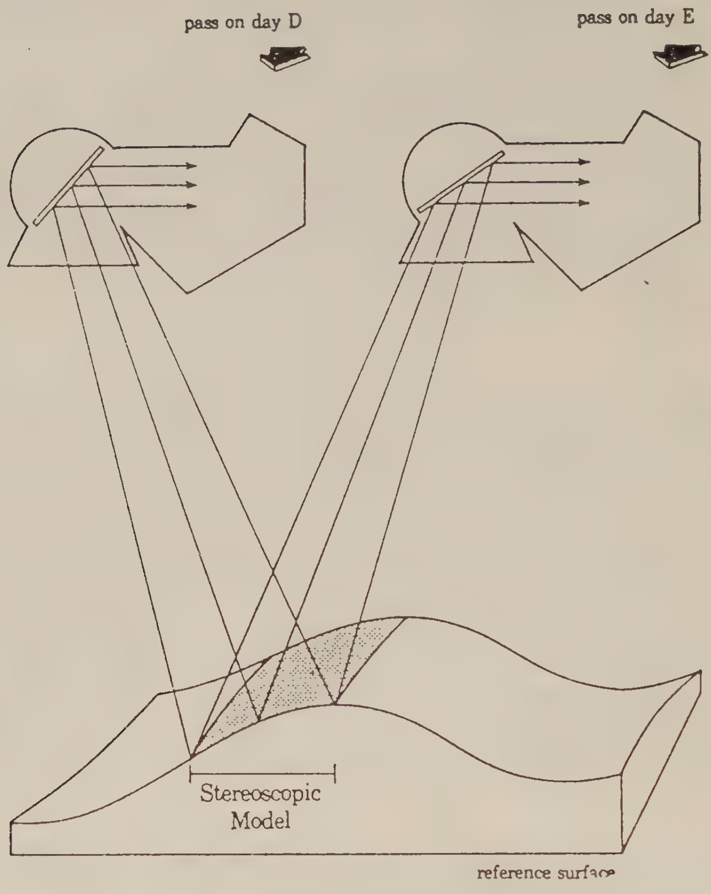


Figure 4.15 Stereoscopic Viewing Capabilities (from SPOT Image Newsletter, 1986)



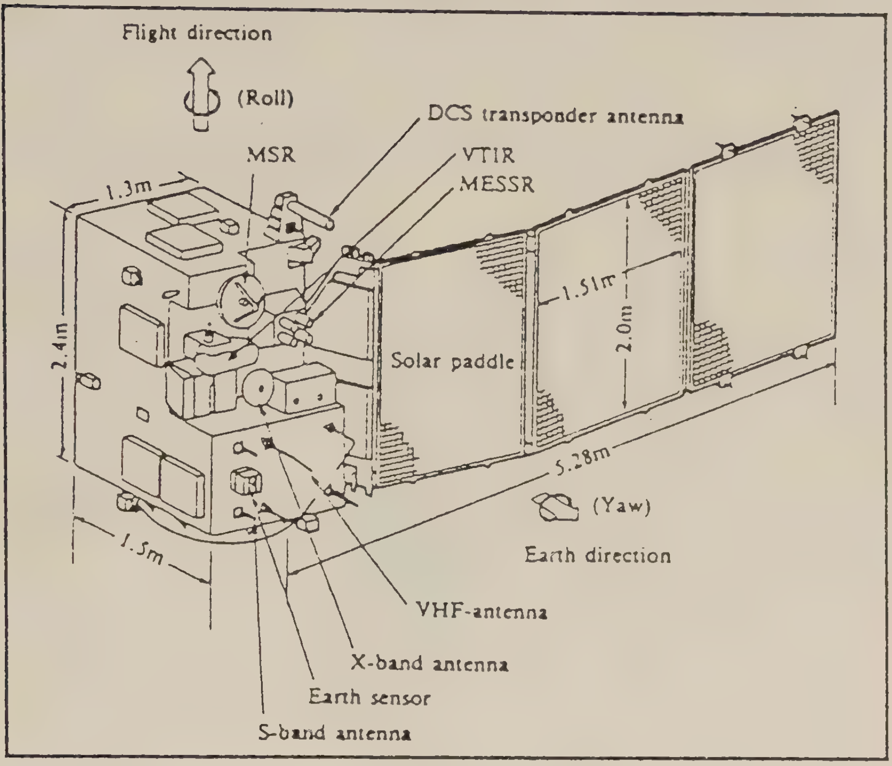
European data from SPOT is received at stations in Toulouse (France) and Kiruna (Sweden). On board recording of data is possible in areas beyond the range of ground receiving stations, for later transmission to Toulouse. Data can be received at stations over a maximum distance of 2 600 kms, and this means that transmissions can last for up to 800 seconds whilst passing a station. Stations are capable of receiving about 250 000 scenes a year. Each day, an observation sequence is loaded into the on-board computer from the Toulouse ground control station. Dissemination of SPOT data is via a commercial company "SPOT Image". SPOT-1 will be decommissioned in September, 1990. SPOT-2, with similar credentials to SPOT-1, was launched in January 1990 and two further satellites in the series are planned before 1998.

4.5.3.3 Marine Observation Satellite (MOS-1)

This was the first Japanese earth observation satellite - it was launched in February, 1987 and has a three-year scheduled life (Figure 4.16). It orbits at an altitude of 908.7 kms, having an inclination of 99.1 degrees and it makes 14 orbits per day. There is repeat coverage every 17 days and it takes 237 orbits to gain a total world wide coverage. MOS-1 does not carry tape recorders and thus ground stations are needed to acquire data which are out of range of the Japanese Earth Observation Centre. The European Space Agency has an agreement with the Japanese Space Development Agency to acquire, process and distribute MOS-1 products in

Europe. MOS-1b, with identical credentials to MOS-1, was launched in February, 1990 and a further four satellites in the series are planned.

Figure 4.16 The Configuration of MOS-1


Flight direction
(Roll)
MSR
DCS transponder antenna
VTIR
MESSR
1.3m
2.4m
1.51m
2.0m
Solar paddle
5.28m
1.5m
(Yaw)
Earth direction
VHF-antenna
X-band antenna
Earth sensor
S-band antenna

4.5.3.4 ESA Remote Sensing Satellite (ERS-1)

ERS-1 is to be the first of a series of satellites, in a programme to be operational in the 1990s, which have been planned by a consortium of countries making up the European Space Agency (ESA). Following its launch in 1991 ERS-1 will be placed in a sun-synchronous orbit and will give global coverage, including the polar regions. It will have an altitude of 777 kms, an inclination of 98.5 degrees and a revolution time of 100 minutes (Figure 4.17). ERS-2 is planned for launch in 1994. Real-time data will be relayed to stations at West Freugh (Scotland), Kiruna (Sweden), Fucino (Italy), Maspalomas (Canary Islands) and Prince Albert (Canada).

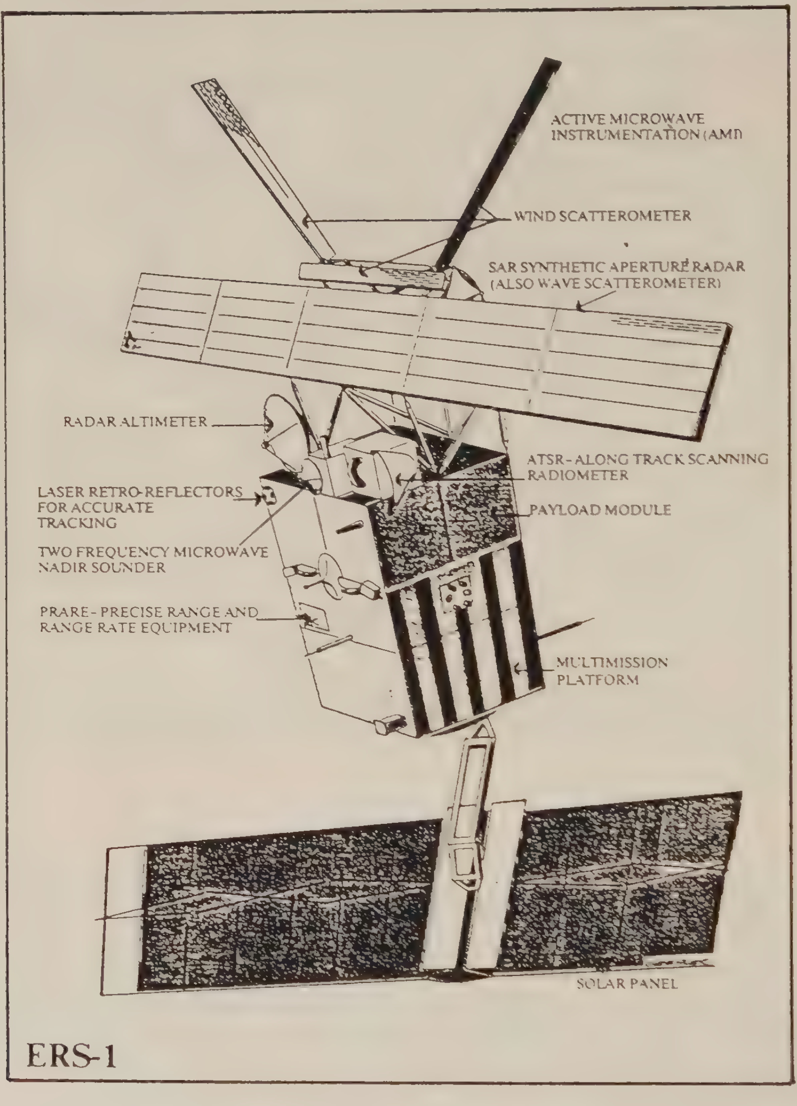
4.5.3.5 Kosmos

This Russian satellite series is a continuation of an older series, and it includes satellites launched for a variety of purposes. It is managed by the "PRIRODA" State Remote Sensing Centre. Soviet officials note that launches in the series occur once every two or three months. The satellites are placed in low (270 kms) orbits and the repeat time for full coverage is 22 days. Their life expectancy varies but it is very short. There is an absence of a network of ground receiving stations.

4.5.4 The Major Environmental Remote Sensors

Here we will be concerned to look first at the main sensors being carried by Landsats 4 and 5, SPOT 1, ERS-1, MOS-1 and Kosmos, including their usual applications. We will then describe two other sensors which have been particularly useful for marine or water based purposes.

Figure 4.17 The Configuration of ERS-1


ACTIVE MICROWAVE INSTRUMENTATION (AMI)
WIND SCATTEROMETER
SAR SYNTHETIC APERTURE RADAR (ALSO WAVE SCATTEROMETER)
RADAR ALTIMETER
ATSR - ALONG TRACK SCANNING RADIOMETER
LASER RETRO-REFLECTORS FOR ACCURATE TRACKING
PAYLOAD MODULE
TWO FREQUENCY MICROWAVE NADIR SOUNDER
PRARE - PRECISE RANGE AND RANGE RATE EQUIPMENT
MULTIMISSION PLATFORM
SOLAR PANEL
ERS-1

4.5.4.1 Landsat 4 and 5 sensors

Both Landsats carry similar sensors and there are two main types:

a) *Multi-Spectral Scanner.* This system is a line scanning device which records from four bands, two in the visible and two in the near infrared spectral bands. The system is comprised of a telescope, a mirror which reflects ground radiation onto a bank of 24 electro-optical sensors, band filters and a sampling system, an internal calibration system and various devices which ensure an orderly stream of digital data for each pixel and spectral band. It images six scan lines in each of the four spectral bands simultaneously giving a 24 scan-line total. Resolution, as delimited by pixel size, is 83 m and a six-bit quantization gives a possible devices which ensure an orderly stream of digital data for each pixel and spectral band. It images six scan lines in each of the four spectral bands simultaneously giving a 24 scan-line total. Resolution, as delimited by pixel size, is 83 m and a six-bit quantization gives a possible range of 64 intensity values. The individually scanned scenes of one MSS image covers approximately 185 x 185 kms and each overlaps its neighbour by about 10%. The original images have a scale of 1:3 369 000 and one frame encompasses 34 000 km^2. Data is recorded on magnetic tape for later transmission to receiving stations and data is available in digital or analogue (photographic) form. Table 4.3 shows details of the bands and possible applications of the imagery.

Table 4.3 Landsat MSS Bands and Applications

Band	Spectral Range	Features/Applications
4	500 - 600 nm Green band	Imagery from this band emphasizes movement of sediment laden water and shallow water bodies, shoals and reefs, etc.
5	600 - 700 nm Red band	Imagery from this band emphasizes cultural features, e.g. urban areas and roads, and sometimes bare soil surface colours.
6	700 - 800 nm Near infrared	This type of imagery emphasizes vegetation and landforms in general.
7	800 - 1100 nm Second near infrared band	This imagery provides best penetration of atmospheric haze, and it emphasizes vegetation and land-water boundaries.

b) Thematic Mapper. This sensor collects, filters and detects radiation in a similar 185 km swath. It records in seven spectral bands which include medium and thermal infrared. It provides a spatial resolution of 30 meters, except on the thermal infrared band, where it is 120 meters. The high spectral resolution is achieved by sensitive detectors and an 8-bit quantization in the analog-to-digital conversion process gives 256 grey levels. The Enhanced Thematic Mapper (ETM), to be launched on Landsat 6, will have an additional 15 meter resolution panchromatic band. Table 4.4 shows the potential application of this sensor by band and wavelength.

4.5.4.2 SPOT-1 sensors

SPOT carries two identical high resolution visible (HRV) scanners, each of which can function independently. They can each scan a strip measuring 60 x 80 kms along the flight line, this width varying with the viewing angle. Every 60 kms the SPOT data is cut to form a scene. The two sensors are designed to operate in either of two modes - panchromatic (black and white) or multi-spectral (colour) in the visible and near infrared spectral bands. The sensors are of the push-broom type. Each consists of a series of fixed linear arrays made up of electronic detectors known as CCDs (charged-coupled devices). Image data are collected by successively measuring the current generated by each detector along the array. In panchromatic mode each individual detector corresponds to one pixel and measures the reflectance of a 10 meter ground resolution cell. In multispectral mode the detectors are paired and thus measure a 20 meter pixel across the track. By doubling the time taken to obtain each sample, the along track measurement of the cell also becomes 20 meters.

Table 4.4 Bands and Applications of the Landsat Thematic Mapper

Band	Spectral Range (micrometers)	Resolution	Features/Applications
TM 1	0.45 - 0.52 visible blue-green	30 m	Bathymetry in less turbid waters, soil/vegetation differences, deciduous/coniferous differentiation, soil types.
TM 2	0.52 - 0.60 visible green	30 m	Indicator of growth rate/vegetation vigour, sedimentation concentration estimates, turbid water bathymetry.
TM 3	0.63 - 0.69 visible red	30 m	Chlorophyll absorption/species differentiation, crop classification, vegetation cover and density, geological applications.
TM 4	0.76 - 0.90 solar near infrared	30 m	Water body delineation, biomass and stress variations.
TM 5	1.55 - 1.75 solar mid infrared	30 m	Vegetation moisture/stress, minerals.
TM 6	10.4 - 12.5 emitted thermal infrared	120 m	Surface apparent temperatures, urban versus land use separation, distinguishing burned areas from water bodies.
TM 7	2.08 - 2.35 solar mid infrared	30 m	Hydrothermally altered zones, mineral exploration, soil type discrimination.

We have already mentioned the nadir, off-nadir and stereoscopic viewing capabilities of the system. The main applications of the stereoscopic imagery are in photogrammetry, for cartographic purposes and photo-interpretation for geological, geomorphological and hydrological studies. SPOT's other applications are largely for land-use studies, the assessment of renewable resources and aiding in mineral and oil exploration.The high resolution makes possible the compilation of topographic maps (at scales of 1:100 000), with the contour interval as little as 20 meters, thematic mapping of between 1:25 000 and 1:50 000 plus the direct compilation of digital terrain models. Table 4.5 gives the main characteristics of the HRV.

Table 4.5 Characteristics of the HRVs on SPOT-1

Characteristics of the HRV instrument	Multispectral mode	Panchromatic mode
3 Spectral bands: green	0.50-0.59 µm	
red	0.61-0.69 µm	
near-infrared	0.81-0.91 µm	
or		
1 Broad spectral band:		0.50-0.75 µm
Instrument field of view	4.13°	4.13°
Ground sampling interval (nadir viewing)	20m x 20m	10m x 10m
Number of pixels per line	3000	6000
Ground swath width (nadir viewing)	60 km	60 km
Pixel coding format	3x8 bits	6 bits DPCM (1)
Image data bit rate	25 M bits/s	25 M bits/s

(1) DPCM (Digital Pulse Code Modulation) is a mode of data compression that does not degrade the radiometric accuracy of the image data (256 grey levels).

4.5.4.3 ERS-1 sensors

The main sensors on board will be:

a) Active Microwave Instrument (AMI) combining the functions of a Synthetic Aperture Radar (SAR), a Wave Scatterometer and a Wind Scatterometer. The AMI will measure wind fields and wave spectra and obtain all-weather images. It will provide for a spatial resolution of 30 meters and have a swath of 99 kms.

b) Radar Altimeter (RA) to measure significant wave height and provide measurements over ice and major oceanic currents.

c) Along-Track Scanning Radiometer (ATSR-M) to determine sea surface temperatures and measure atmospheric water vapour.

d) Precise Range and Range Rate Experiment (PRARE) for accurate satellite ranging and to allow ionospheric error correction. The programme objectives include the global observation of: waves; sea state; ocean currents; ocean waves; sea surface temperatures; sea ice; ice sheet dynamics, and also to provide imaging of land by SAR. These objectives will help with shipping, fisheries and offshore activities.

4.5.4.4 MOS-1 sensors

The details of the three sensors on board MOS-1a and 1b are given in Table 4.6. MOS is intended to establish fundamental technologies for earth observation satellites, primarily by observing oceanic phenomena such as ocean colour and temperature. The satellite observations are also expected to be of value to agriculture, forestry, fishery and environmental preservation.

Table 4.6 Bands, Features and Objectives of MOS-1 Sensors

	MESSR	VTIR		MSR	
Objective	sea surface colour, vegetation, land use, etc.	suspended sediment	stratospheric water vapour, Earth and sea surface temperatures	water vapour content, liquid water content, ice, snow etc.	
Observation Wavelength (μm)	0.51 - 0.59 0.61 - 0.69 0.73 - 0.80 0.80 - 1.10	0.5 - 0.7	6 - 7 10.5 - 11.5 11.5 - 12.5		
Observation Frequency (GHz) Beam Width Integration Time (m sec)				23.8±0.2 1.89±0.19 10 & 47	31.4±0.25 1.31±0.13 10 & 47
IFOV (km)	0.05	0.9	2.7	32	23
Swath Width (km)	100 (each optic)	1500		317	

4.5.4.5 Kosmos sensors

Satellites in the series have carried different sensors and combinations of sensors. Of most interest for environmental observations are their cameras, details of which are shown in Table 4.7. The KFA-1000 provides for a ground resolution as small as 5 meters, giving it a great advantage over SPOT or Landsat. Another advantage is the frequency of cover. 98% of all PRIRODA's RS imagery is obtained from a combination of the three cameras carried on Kosmos satellites. After imaging in space, the exposed film is soft-landed to earth for processing.

Table 4.7 Specification of Cameras Carried by Kosmos Satellites (from Morrison and Bond, 1989)

Type of camera Type of survey	Average orbit height (km)	Average image scale	Number of spectral zones	Spectral range (nm)	Image format (cm)	Area of coverage (km)	Endlap of images (%)	Ground resolution (m)
KFA-1000 Band-specific, color[a]	270	1:270,000	Band-specific	570–680 680–810	30 × 30	80 × 80 (6400)	60	5
MK-4[b] Multispectral and color band-specific	200–350	1:650,000– 1:1,200,000	3	(1) 635–690 (2) 810–900 (3) 515–565 (4) 460–505 (5) 580–800 (6) 400–700	18 × 18	117 × 117 (13,700) 216 × 216 (46,700)	60	6–8
			1	570–680 680–810				
KATE-200 Multispectral	270	1:1,350,000	3	500–600 600–700 700–850	18 × 18	243 × 243 (59,000)	60	15–30

[a] The survey is performed by two cameras, each of which surveys a swath of territory to the left or right of the axial line of movement. As a result imaging by each camera occurs with a deviation of 8° from the vertical.

[b] The MK-4 camera has 4 lenses, which survey one and the same area simultaneously. Black-and-white imaging is performed in 3 spectral bands (from 6 possible alternatives) depending on the films and filters used and color band-specific imaging is done on two-layer film in one spectral band (from 2 possible alternatives).

4.5.4.6 Other sensors of interest to aquaculture and inland fisheries

There have been a number of other satellite sensors launched in the past two decades which have been of potential value to aquaculture and inland fisheries. We will briefly describe two of these:

A) *The Heat Capacity Mapping Radiometer (HCMR).* This sensor was launched as part of the Heat Capacity Mapping Mission in April 1978 and operated until September 1980. The sensor was a two channel scanning radiometer operating in the visible and near infrared band and the thermal infrared band. The main objectives of interest were:

i) The mapping of natural and man-made thermal effluents.
ii) The detection of thermal gradients in water bodies.
iii) The mapping and monitoring of snow fields for water run-off prediction.
iv) The monitoring of marine oil pollution.

Many of the products obtained from this mission are still available.

B) *The Coastal Zone Colour Scanner (CZCS).* This was launched aboard Nimbus-7 in October 1978 and was operational until late 1984. The CZCS was a multi-spectral line scanner, optimized for use over water. It collected quantitative information on ocean colour, suspended sediments, chlorophyll concentrations, pollutants and temperature from the upper few meters of water. Both photographic and digital data are still available. Table 4.8 sets out the bands and measurements of CZCS.

Table 4.8 Bands and Measurements of the CZCS Sensor

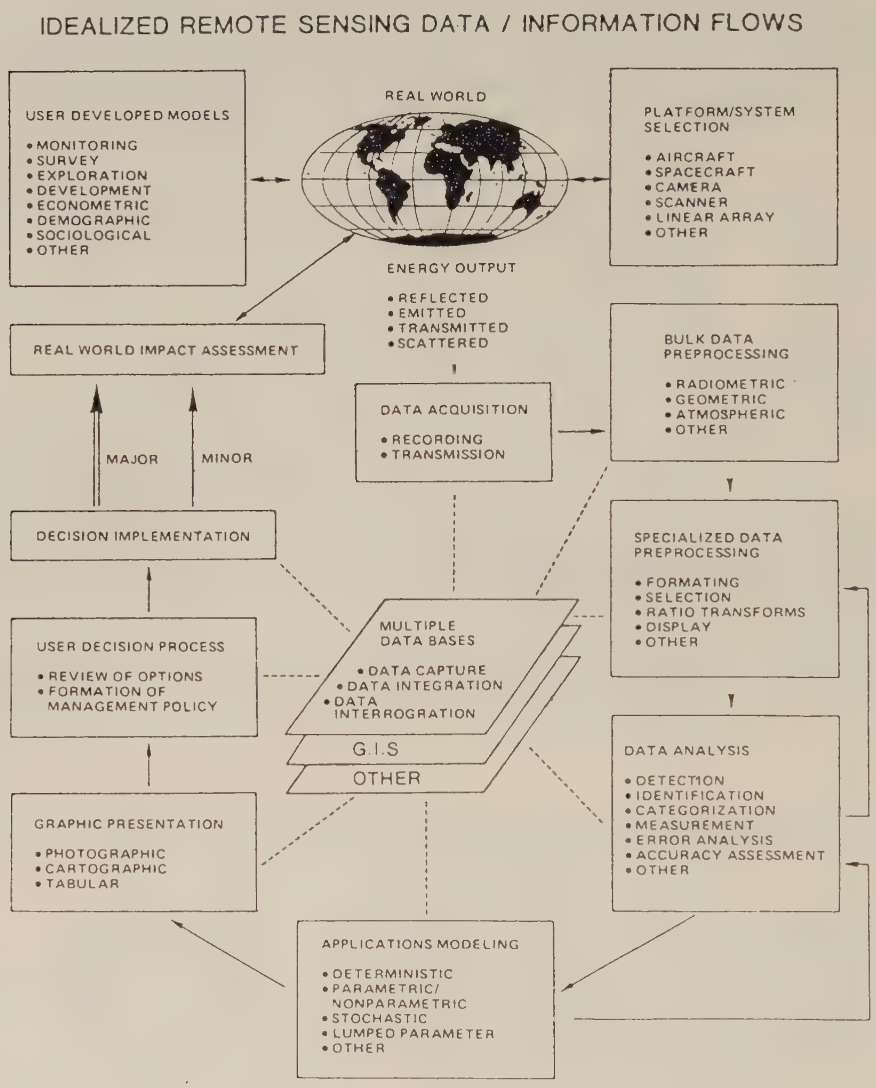
Sensor:
Coastal Zone Colour Scanner (CZCS)

	Wavelength (μm)	Spatial Resolution	Swath Width	Measurements
Band 1	0.43- 0.45	800m	1800km	chlorophyll absorption
Band 2	0.51- 0.53	800m	1800km	chlorophyll distribution
Band 3	0.54- 0.56	800m	1800km	gelbstoffe (yellow substance)
Band 4	0.66- 0.68	800m	1800km	chlorophyll concentration
Band 5	0.70- 0.80	800m	1800km	surface vegetation
Band 6	10.50-12.50	800m	1800km	surface temperature, diffuse attenuation co-efficient

4.6 Data Processing of Remotely Sensed Imagery

The electronic images which have been captured by RS devices are either transmitted directly to earth or are stored in on-board recorders for later transmission. This represents the initial stage in a complex information flow which is depicted in Estes (1985) (Figure 4.18). The data scanned are retained in the form of pixel values, with each value representing the amount of radiation (the spectral reflectance) within a given band-width received by the scanner from the area of the earth's surface covered by the pixel. Pixel values are digitally coded by a certain number of bits, i.e. Landsat and SPOT use 8-bit codings which give a range of 256 possible values, and the values for any one pixel will change according to particular spectral bands being recorded. The area covered by a pixel (the resolution) is a function of the height of the sensor, the focal length of the lens or focusing system, the wavelength of the radiation and other inherent characteristics of the sensor itself. Each pixel will be allocated a co-ordinate in a grid referencing system.

Figure 4.18 The Flow of Information in the Remote Sensing System


IDEALIZED REMOTE SENSING DATA / INFORMATION FLOWS
USER DEVELOPED MODELS
• MONITORING
• SURVEY
• EXPLORATION
• DEVELOPMENT
• ECONOMETRIC
• DEMOGRAPHIC
• SOCIOLOGICAL
• OTHER
REAL WORLD
PLATFORM/SYSTEM SELECTION
• AIRCRAFT
• SPACECRAFT
• CAMERA
• SCANNER
• LINEAR ARRAY
• OTHER
ENERGY OUTPUT
• REFLECTED
• EMITTED
• TRANSMITTED
• SCATTERED
REAL WORLD IMPACT ASSESSMENT
BULK DATA PREPROCESSING
• RADIOMETRIC
• GEOMETRIC
• ATMOSPHERIC
• OTHER
DATA ACQUISITION
• RECORDING
• TRANSMISSION
MAJOR
MINOR
DECISION IMPLEMENTATION
SPECIALIZED DATA PREPROCESSING
• FORMATING
• SELECTION
• RATIO TRANSFORMS
• DISPLAY
• OTHER
MULTIPLE DATA BASES
• DATA CAPTURE
• DATA INTEGRATION
• DATA INTERROGRATION
G.I.S
OTHER
USER DECISION PROCESS
• REVIEW OF OPTIONS
• FORMATION OF MANAGEMENT POLICY
DATA ANALYSIS
• DETECTION
• IDENTIFICATION
• CATEGORIZATION
• MEASUREMENT
• ERROR ANALYSIS
• ACCURACY ASSESSMENT
• OTHER
GRAPHIC PRESENTATION
• PHOTOGRAPHIC
• CARTOGRAPHIC
• TABULAR
APPLICATIONS MODELING
• DETERMINISTIC
• PARAMETRIC/ NONPARAMETRIC
• STOCHASTIC
• LUMPED PARAMETER
• OTHER

The pixel values are transmitted to earth (downlinked) as a stream of binary numbers. To reconstitute the images, ground based computers decode the binary data, allocating the appropriate colour tone to each pixel value. The images can then be displayed on a monitor or in some print-out form. At the initial stage they will be monochrome and in a pre-processed state. To perform image analysis processes there is a vast selection of computer hardware and software systems, for micro, mini or mainframe computers, which we cannot explore here but which Jensen (1986) reviews in some detail. These software systems should be capable of executing all, or a number of, specific processing functions, as shown in Table 4.9. Not all of the functions shown are essential, i.e. this will depend on the type of output required. We will describe here only the essential functions plus those more commonly used. Images from Landsat and SPOT can be purchased at various "levels" of processing.

Table 4.9 Image Processing Functions Found in Many Image Processing Systems (from Jensen, 1986)

- Preprocessing
  - A. Radiometric correction (for system and environmental effects)
  - B. Geometric correction (image to map or image to image)
- Display and enhancement
  - C. Black-and-white display
  - D. Color composite display
  - E. Density slice
  - F. Magnification or reduction
  - G. Transects
  - H. Contrast stretch
  - I. Image algebra (band ratioing, differencing, etc.)
  - J. Spatial filtering
  - K. Edge enhancement
  - L. Principal components
  - M. Linear combinations (e.g., Kauth transform)
  - N. Texture transforms
  - O. Fourier transforms
- Information extraction
  - P. Supervised classification
  - Q. Unsupervised classification
  - R. Contextual classification
  - S. Incorporation of ancillary data in the classification
- Geographic information systems (GIS).
  - T. Raster- or image-based GIS
  - U. Vector- or polygon-based GIS (must allow polygon comparison)
- Integrated systems
  - W. Complete image processing systems (functions A to S)
  - Y. Complete image processing systems and GIS (functions A to S and T or U)
- Utilities
  - Z. Mainframe communication for micro- or minicomputer-based systems

4.6.1 Image Pre-Processing

The two functions involved here, radiometric and geometric corrections, will be essential if meaningful output is to be obtained. They are essential because there are a number of factors inherent in the RS system which contribute to the images being distorted in some way. These factors include:

a) Changes in the attitude, velocity and altitude of the sensing platform.
b) The forward motion of the platform causes scan skew.
c) The scanners (in Landsat) do not have a constant scan velocity.
d) The area covered by one pixel will have its shape distorted when viewing at an oblique angle.
e) The geometry of the images is affected by the earth's rotation, its curvature and atmospheric refraction.
f) Radiometry is affected by the sensor, e.g. sensor "noise" and poor calibration between detectors, by the atmosphere, e.g. presence of aerosols and scattering effect, and by the scene itself, e.g. effect of relief on reflection and type of reflection of the object.

A) *Radiometric Correction.* Detector sensitivity will slowly change over time, making some detectors more or less sensitive to radiance than its neighbours. This results in images which have a "banding" or striped pattern which needs correcting. This effect can occur in both mechanical or push broom scanners, as can "pixel drop" when individual pixel radiance is not recorded. Radiometric distortions (atmospheric attenuation) is also a problem as radiance is altered by the atmosphere through which it passes. This is especially a problem over water when there is a lot of atmospheric water vapour, i.e. radiance reaching the detector may be 20% from the water, 80% from the atmosphere. There are various correction methods, some of which are described in Butler *et al* (1988).

B) *Geometric Correction.* This will involve several levels of pre-processing. The data has first to be corrected for earth curvature, earth rotation and satellite attitude errors. After this the image may still contain geometric distortions, with the center of the scene located to an accuracy of only a few kilometers. To improve this, a sufficient number of ground control points, which are readily identifiable on the image and on a map, are selected for calculations of a least-square fit, and the results are then used to adjust the image to the map co-ordinates. Maps of different projections, e.g. Mercator, Peter's, Conformal Lambert, etc., can be used.

4.6.2 Image Display and Enhancement

There are a large number of functions which can be further performed on the digital data in order to meet specific requirements. Enhancements are designed to aid the analysis of images and pictures so that the maximum use can be made of them, e.g. the use of colour rather than grey tones means that more discrimination can be applied. We cannot examine all display and enhancement techniques, but some are shown in Figure 4.19 and the major ones are described:

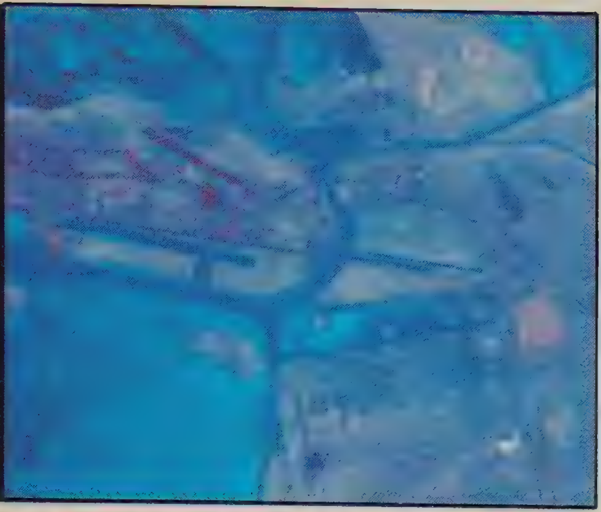
A) *Contrast Stretching.* Sensors are designed to record a full range of values from a very strong signal (usually displayed as white) to no signal (black), with in-between some 254 grey tone steps. Few scenes require such a dynamic range and data values for any scene tend to occupy less than half of the available range. The values can be changed to occupy the full scale by using a stretch programme that can be applied to give a linear, uniform distribution, gaussian or other arbitrary stretch.

B) *Edge Enhancement.* This technique can be visualized as using the computer to recognize subtle but sudden steps in the grey scale, where the sudden step in local grey scale is continuous over a regional variation in background digital values. Its effect is to increase the grey scale of the step so that its edge is more clearly displayed. It is particularly useful for the detection of linear elements, either oceanic (warm or cold water fronts) or man-made (canals, waterways, etc.).

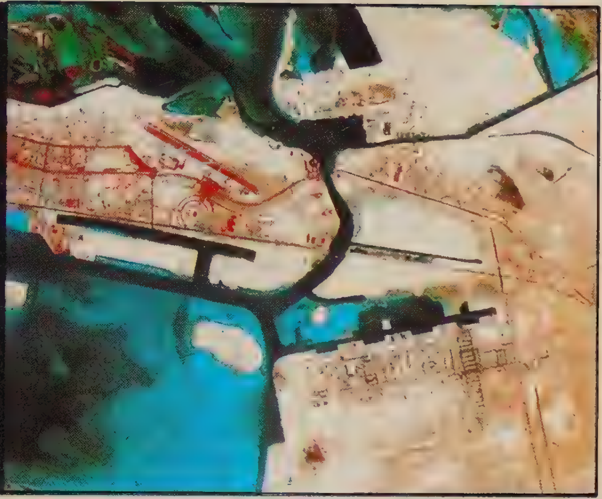
C) *Density Slicing.* This involves delineating the different ground features by colour coding, i.e. areas having similar reflectance values are assigned to one colour. Up to eight "slices" might be taken through the range of pixel values which would produce an image showing eight key features in eight colour ranges. The computer can calculate when to best define a threshold to separate individual colours and it can also calculate the area covered by the different features (colours or colour tones). It can be particularly useful in water depth analyses. A simpler way of using colour is to select three spectral bands and feed the data from each through a different colour gun on the image processors monitor. This results in either a natural-colour or false-colour composite. False-colour indicates that colours have been assigned to information sensed in bands which are beyond the visible range, i.e. they simulate radiation which cannot be seen.

Figure 4.19 Some Important Image Processing Techniques

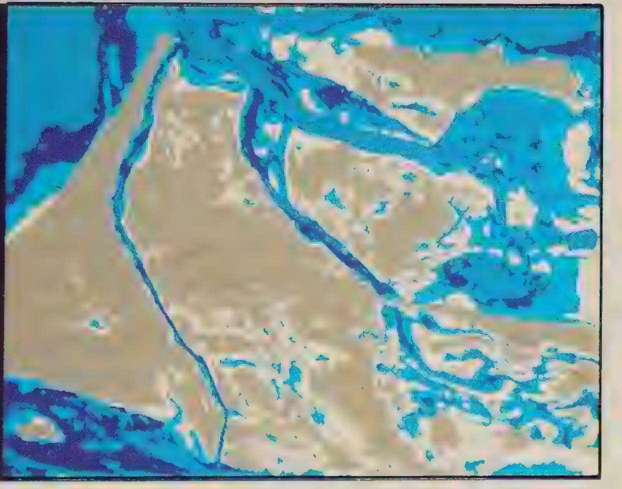
1



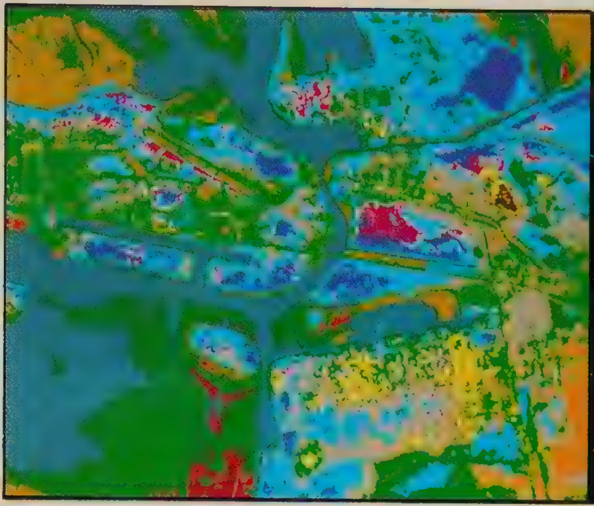
2



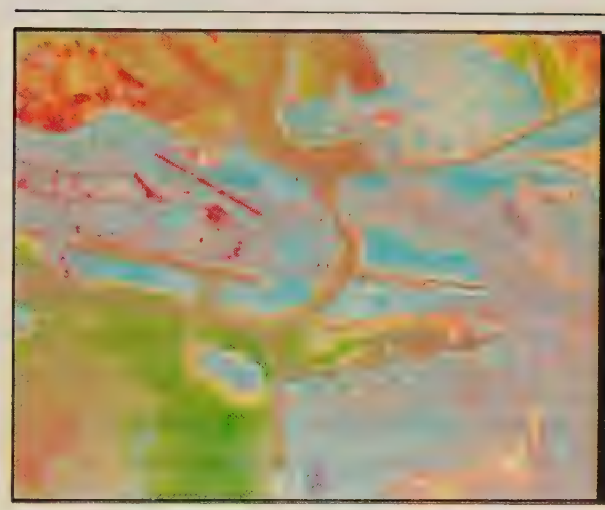
3



4



5



Extracts from a Landsat 5 Thematic Mapper image of Abu Dhabi, U.A.E. recorded on 21 April 1984.

1. raw data – colour composite of bands 2, 3 and 4
2. contrast stretched and edge enhanced
3. density sliced and smoothed
4. maximum likelihood classification of all 7 bands resulting in 16 land cover classes
5. principal components image

D) *Spatial Filtering*. This term includes a family of operations which use values for groups of pixels to spatially filter areas to produce images with different effects such as smoothing, or line enhancement. For example, "low pass" filters assign to each pixel of the radiance values to be suppressed. On the other hand "high pass" filters can enhance differences of reflectance values in the image.

E) *Principle Component Analysis (Data Compression).* This analysis compresses multi-spectral data sets as an aid to image classification and pattern recognition. The normally highly correlated spectral bands are transformed into a new set of variables or components that are uncorrelated. The new components represent more efficiently the variance of the data set. Using Landsat MSS data the first two principle components generally account for over 95% of the original variance, although lower order components may include useful image detail.

F) *Image Classification*. Spectral classification techniques can be grouped into supervised and unsupervised classifications. We can only briefly describe classification here - details are given in Lantieri (1988). If a RS user wishes to classify all the tones on an image which have a certain range of, for instance, crop categories, then by finding out the typical pixel values for each crop (using field investigations), the findings can be applied to the rest of the image, i.e. the computer can be "trained" to seek out various spectral signatures for one small area and then apply it across the image. Several different statistical methods are available for determining how to allocate pixel values to categories. Image classification is usually successful if the targets are spectrally very different; unfortunately in most land use analyses many crops register similar pixel values.

G) *Multi-Temporal Analysis (Change Detection).* Data sets collected at different dates (multi-date) or at different times (multi-temporal) of the same day can be registered and compared pixel by pixel. The pixel value of each pair can then be ratioed or subtracted. Other procedures can also be used, such as the statistical procedures of Principle Component Analyses, to compose the multiple data sets. The resulting digital numbers will highlight differences between the images. This is of particular use in studies of crop state, seasonal vegetation anomalies, rivers, thermal changes, coastal processes, etc.

H) *Digital Mosaics*. A display application of interest is the "patchworking" of images from the same sensor to form mosaics covering large areas. This poses radiometric and geometric problems since the selected scenes may have been imaged at different seasons of the year, i.e. when colour balances are different. Mosaics are of value in studying regional features of land cover, geology, natural resources and in cartography.

4.7 The Potential Applications of Remote Sensing to Aquaculture and Inland Fisheries

In this section we will look at how RS might be applied to the development and management of aquacultural and inland fisheries. The accent will be on potential applications rather than actual applications since examples of the latter will be given in Chapter 7, and because one of our basic aims is to exemplify ways in which RS can be of use in areas where location optimizing suffers from a lack of existing data. Our approach will be from the viewpoint of examining the individual production functions and to see how far RS methods might be applied. In doing this there will clearly be instances where remotely sensed data can be used directly, but there will be many more instances where various "proxy" remote data, or as Kapetsky and Caddy (1985) call it, "inferred" data, can be used. For most usable images a degree of "ground truthing" would be desirable and the extent to which this is necessary will vary greatly from function to function.

Again, we will concentrate here upon images obtained from satellite-based sensors since these are the most widely available, they are able to give wide area coverage, they may be available for many time periods and they are potentially cost-effective. However, given the restricted resolution available, we will be discussing location optimization on the macro rather than micro scale. For micro scale analysis airborne sensors are particularly useful and they would be especially important for specific site selection and for other purposes such as monitoring existing fishing levels or for any micro environmental analyses.

By the end of this section the reader should be able to assess the extent to which RS can help in providing information for the management and development of fisheries and aquaculture. Clearly, there are many functions which can never be aided by RS, and for these land-based detection methods will always be applicable. Cheney and Rabanal (1984) note that the decision to use RS for aquaculture siting should be based on a number of factors:

a) The total land and water area to be assessed - is it large or small?
b) The anticipated diversity of the environment to be surveyed - is it homogeneous or varied?
c) Existing development - has the area been extensively modified or is it still relatively natural?
d) Are there any legal/political/institutional constraints - has land been designated for specific purposes?
e) What is the status of any existing information for a specific area?

Though we will exemplify many potential RS applications, Cheney and Rabanal (1984) also provide a comprehensive list, as does Pettersson (1989), and Cordell and Nolte (1988a) provide a discussion of the problems of applying RS to aquaculture and inland fisheries location.

4.7.1 Water Quality

In section 2.3.1 we saw that a large number of variables may influence water quality, and thus potential fish productivity. Though it is not yet possible to use RS techniques to detect variations in most of these qualitative factors, it is possible to gain a number of inferences as to water quality, e.g. by looking at:

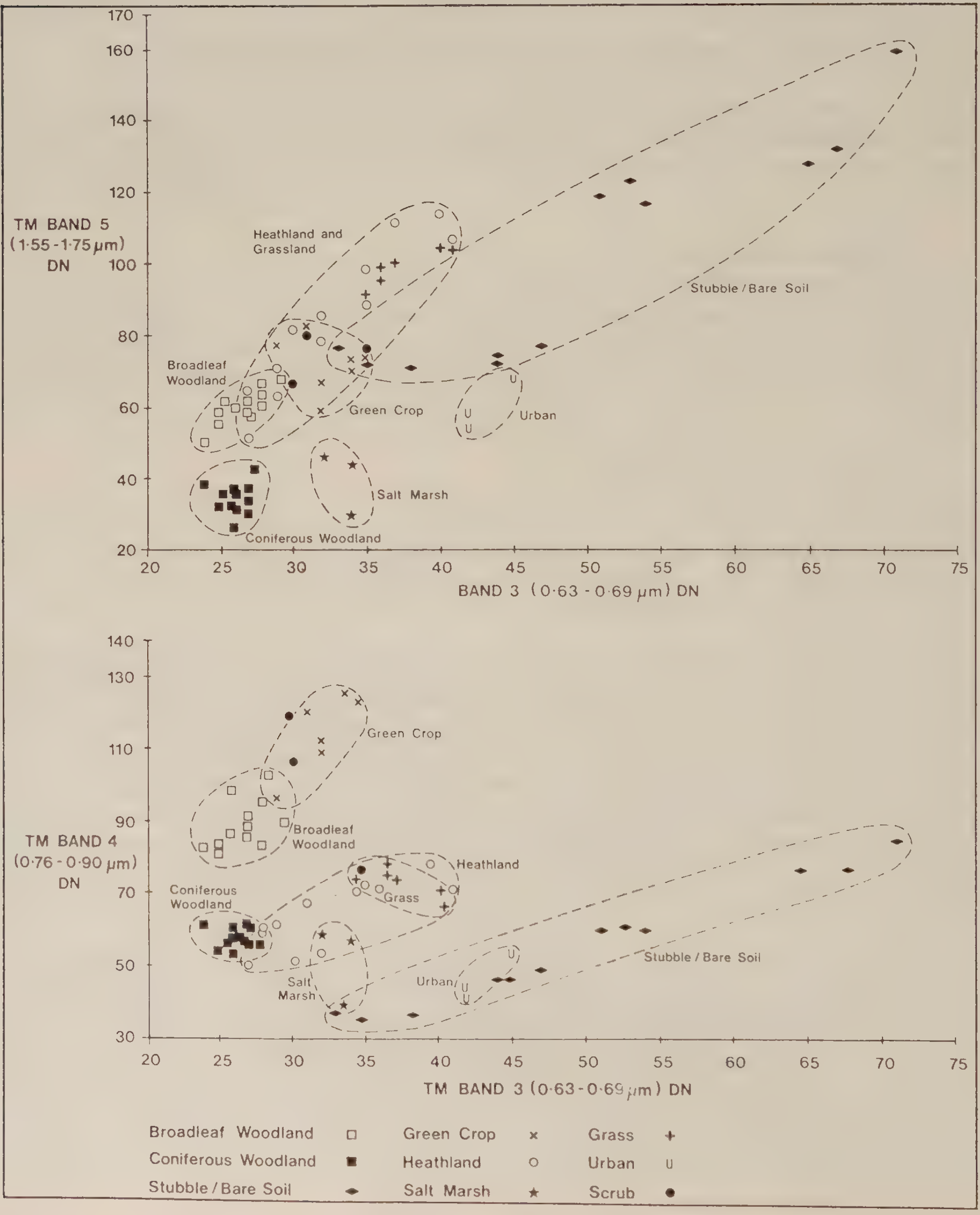
i) Areas affected by acid rain.
ii) Land use and crop yields.
iii) Effluent discharges and other pollutants.
iv) Suspended and cohesive sediment concentrations.
v) Salinity.
vi) Phytoplankton concentrations.

Because some of these variables exhibit similar radiometric values, it has proved necessary to establish various empirical models to show the relationship between water radiance values and different environmental parameters. Even when these models have been verified they are not always globally valid. Further problems with assessing water quality via RS exist, such as the fact that the spatial resolution is insufficiently detailed for most river assessment and the fact that most radiance values will only refer to near surface water. Additionally, since many water qualitative parameters undergo frequent changes, the monitoring frequency from satellite-derived data is insufficient, and indeed even "real time" images may not be real enough in the case of some pollutants.

A) *Acid Rain.* It is recognized that this is an increasing problem in several major world regions, and that areas where vegetation is showing signs of damage will also exhibit water having adverse acidic conditions. Using Landsat TM imagery obtained over southern Germany, in the wavelengths of 0.75 to 1.3 um, damage assessment could be determined since affected trees gave significant spectral changes. Information derived from reference data on tree species, age, degree of damage, etc., is being used to train and test image classification and for the interpretation of results.

B) *Land Use and Crop Yields.* Trolier and Philipson (1986) have shown the feasibility of again using TM scenes, only this time by visual analysis, to determine classes of land use (from 22 different classes) which could have a major effect on the quality and quantity of watershed run-off. This proved quite successful using TM Bands 3,4 and 5 or a composite of them. Clearly, different land use types will give clues as to the likely degree of pollution to be expected, though it would be wise to seek verifiable data to back up that gained from remotely sensed imagery. Larger urban and industrial areas can readily prove to aggravate water quality as can areas having intensive farming with high crop yields. Also areas which have exploitive activities such as mining, quarrying or forestry are likely to be qualitatively affected. Most land uses which lack human intervention are easily detected and would exhibit better quality water. Figure 4.20 gives examples of land use reflectance values from TM data.

Figure 4.20 Mean Reflectance Values for Several Categories of Land Use



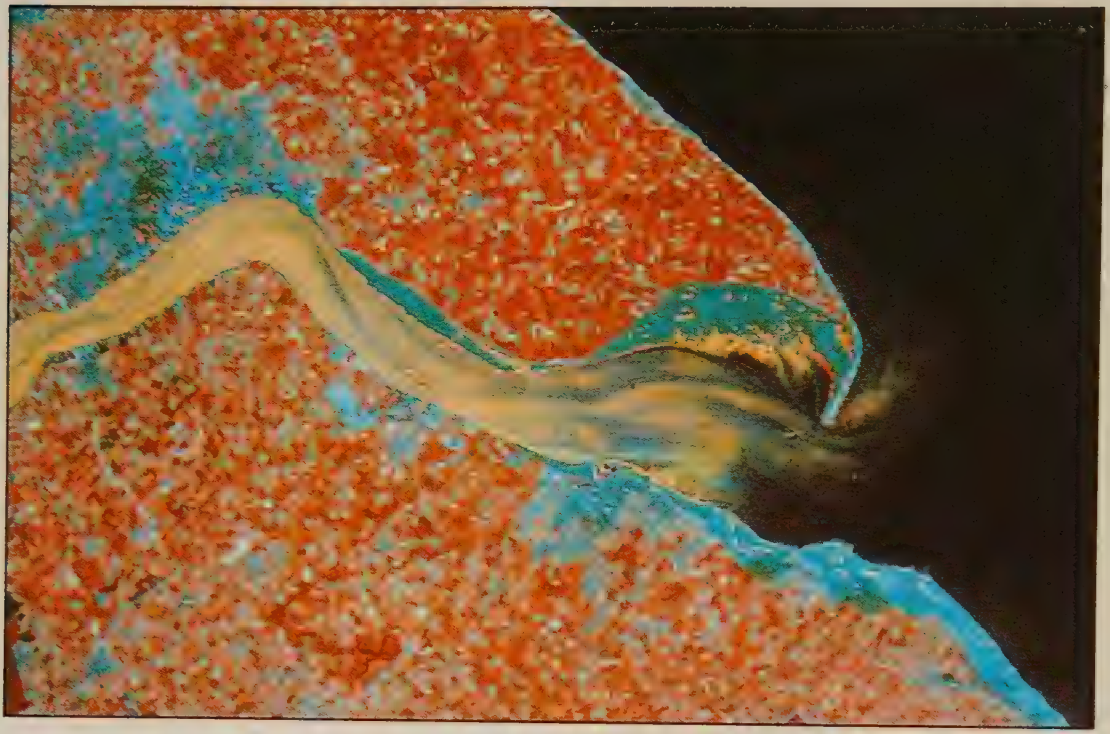
C) *Effluent Discharges and Other Pollutants.* RS techniques are practicable for the detection of high volume effluents whose spectral characteristics are markedly different from the surrounding water, e.g. effluents which are highly coloured or at elevated temperatures. Examples of pollutants monitored from satellites include sewage sludge dumped at sea, sewage outfalls, titanium dioxide and oil discharges, spills or blowouts. Figure 4.21 illustrates both high suspended sediment loads and a titanium dioxide effluent plume. Scanners used successfully to detect pollutants include MSS, CZCS, microwave detection by SMMR and SAR, fluorescence detection by LIDAR (laser-radar) and thermal detection by IR scanner.

D) *Suspended and Cohesive Sediment Concentrations.* Radiation in the visible part of the spectrum penetrates significantly below the water surface where it is absorbed and scattered. The presence of suspended particles causes much "backscatter", giving the water a cloudy appearance. The Landsat MSS, the SPOT HRV and the CZCS have all allowed false-colour composite images to be prepared which clearly highlight sediment concentration and plumes (see Figure 4.21). A colour slice enhancement from a single band (of the MSS) has been used to quantitatively map sediment concentrations (Figure 4.22), though reliable calibration requires the collection of water samples at the time of the satellite overpass. Sediment concentrations can be used as natural tracers to identify water movement and frontal boundaries. Cheney and Rabanal (1984) report much of the work done on the measurement of suspended sediment concentrations from satellite data, warning that there is an identity overlap with information on chlorophyll content. Ritchie and Cooper (1988) report the success of the satellite monitoring and estimation, using Landsat MSS data, of sediment concentrations in small inland water bodies.

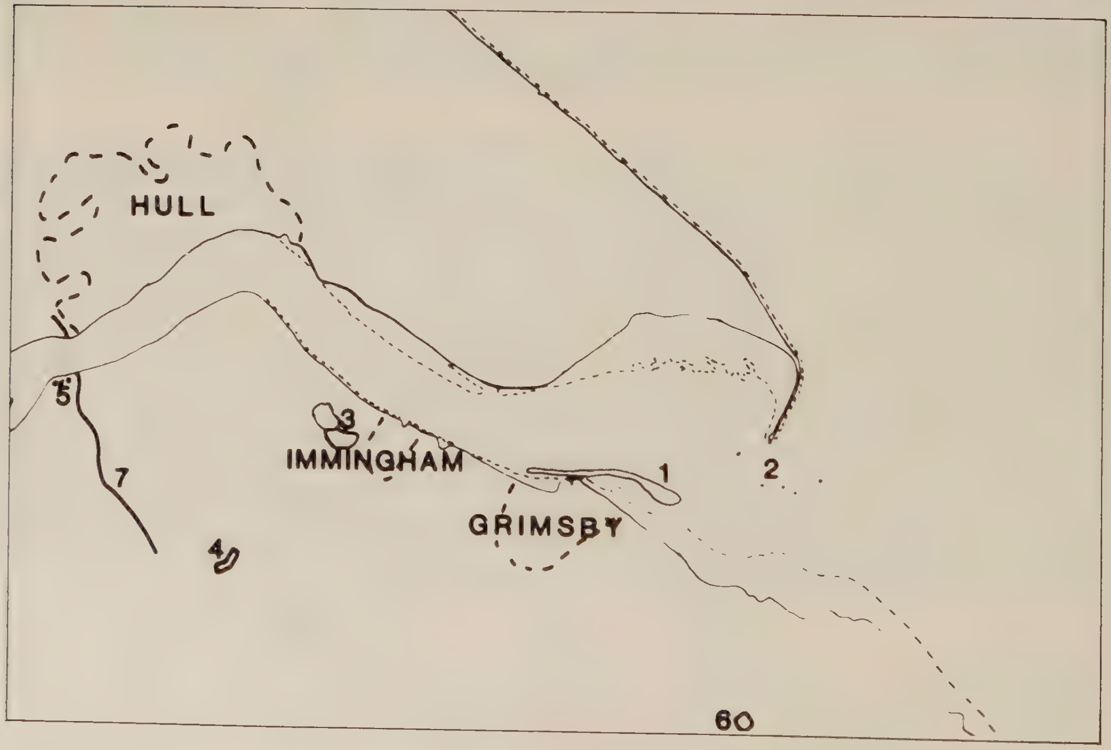
E) *Salinity.* Both Butler *et al* (1988) and Cordell and Nolte (1988b) report that salinity level measurements from satellite data are not yet recorded in the literature, but that they are certainly feasible with the use of microwave sensors, i.e. changes in salinity cause significant changes in the emissive brightness temperature of water for frequencies less than 5 GHz. The measurement of this brightness should be adequate for mapping the near-surface spread of freshwater at a river mouth or estuary. Although salt wedges at some depth could not be plotted, brightness measurements could be a great help in site selection for many forms of aquaculture, both in saline conditions and at the mariculture/freshwater interface.

F) *Phytoplankton Concentrations.* This water qualitative factor is certainly the best documented, possibly because detection is both very important and it provides dramatic large-scale imagery which is not usually visible, e.g. occurrences of significant algal blooms in the northern Adriatic and the Scandinavian Skagerrak area (Figure 4.23). The presence of phytoplankton is detected by their green pigment (chlorophyll) - increasing quantities cause water colour to change from blue to green. Phytoplankton presence can be considered as an index of biological productivity and it can be related to fish production - in moderate amounts it is ideal, but when so-called algal blooms occur the planktonic concentrations are sufficient to reduce dissolved oxygen levels dramatically, often resulting in massive fish kills. The spectral reflectance of algae is quite distinctive in the near infrared range. MSS measurements along with field data sampling, allow for the calibration of algal concentrations, and estimates of algal front movements can be reliably made (Petterson, 1989). Phytoplankton quantitative estimates have been successfully made in lakes as well as in the sea, and several sensors have been used for detection, e.g. MSS, CZCS and an Ocean Colour Experiment (OCE) instrument.

Figure 4.21 Effluent and Sediment Yields in the Humber Estuary in Northern England



Landsat-1 image of the Humber estuary, UK 27 June 1976



1 Effluent plume from factory producing titanium dioxide
2 Ships at anchor in the outer estuary
3 Oil refineries
4 Quarry
5 Clay pits
6 Covenham reservoir
7 A15 (to Humber bridge) under construction

Figure 4.22 Colour Slice Enhancement Showing Suspended Sediments Which Allows the Quantitative Map to be Compiled

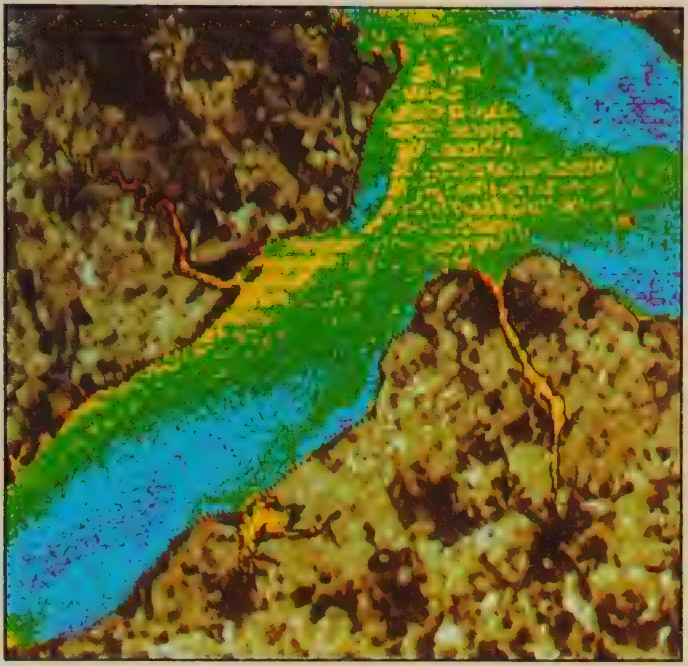


Fig 3 Colour-slice enhancement of Landsat 2 MSS band 5–19 Aug 1978

A colour slice
hancement of a single Landsat MSS band
3), not only shows up the suspended sedi-
nt distribution patterns, but is capable of
antitative calibration as a map of suspended
iment concentration (fig 4).

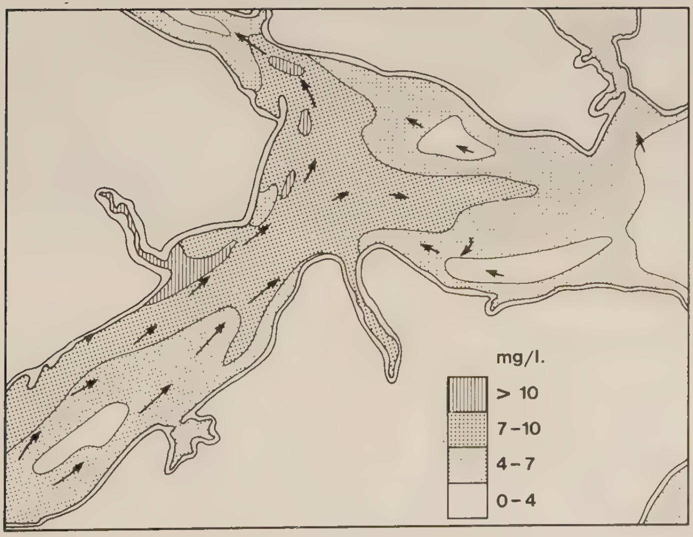
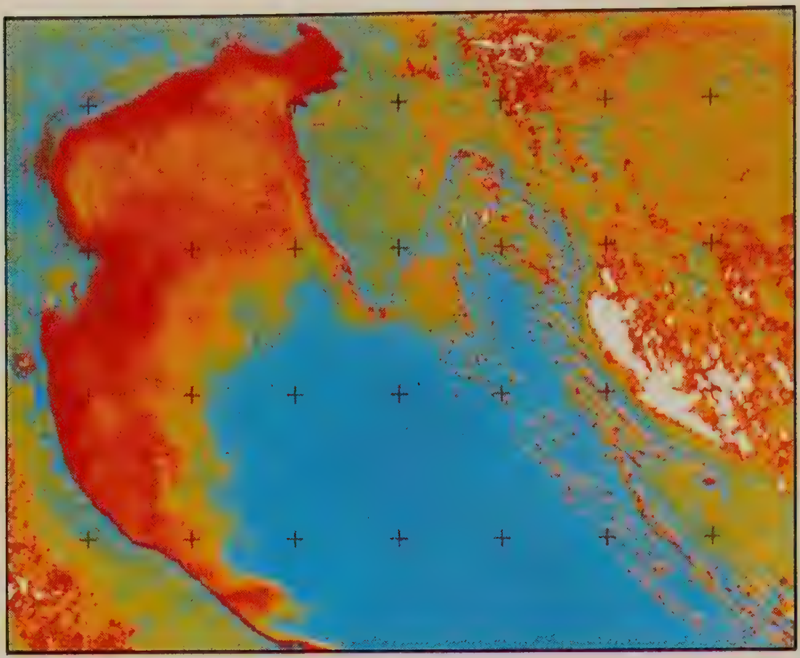


Fig 4 Map of suspended sediment at 10.00 GMT 19 Aug 1978 (2 hrs before high water, Portsmouth) based on fig 3. Arrows show tidal stream.

Figure 4.23 CZCS Composite of Bands 1, 2 and 3 of the Northern Adriatic Showing Chlorophyll Concentrations in Orange



CZCS composite of bands 1, 2 and 3 of the Venice lagoon showing chlorophyll concentrations - high amounts in red, low in blue.

4.7.2 Water Temperature

A number of sensors, working in the thermal spectral range of 2 to 18 um, are capable of detecting surface water temperatures. The main sensors used to date have been the MSS, CZCS, AVHRR, SMMR and the TM. Sea surface temperature (SST) sensors operate from both geostationary and orbiting satellites. Since data obtained from the GOES geostationary satellite necessarily has a large spatial resolution (8 kms), it is only useful for sea, large lake or oceanic (macro-scale) areas, though on the plus side data can be obtained at 30 minute intervals. For smaller water bodies, the AVHRR instruments aboard the NOAA satellite series is most frequently used. It offers a spatial resolution of about 1.1 kms and a thermal resolution of 0.2 degrees C. Many SST algorithms have been developed by NOAA and tested in a wide variety of situations, and the validity of satellite-derived SST data is now widely recognized for bodies of water of various sizes (Robinson and Ward, 1989). For smaller bodies of water

Band 6 of the TM on-board Landsats 4 and 5, has provided satellite thermal imagery at a resolution of 0.12 kms. An example of TM data (Figure 4.24) clearly shows a well developed thermal plume emanating from a power station in the N.E. corner of a lake. The actual or relative temperature gradients can be calculated and the movement of the plume correlates strongly with wind direction. Since SST data has been collected over a long time, NOAA now publish comprehensive real time and long-term water temperature maps covering many areas of the world.

4.7.3 Water Quantity

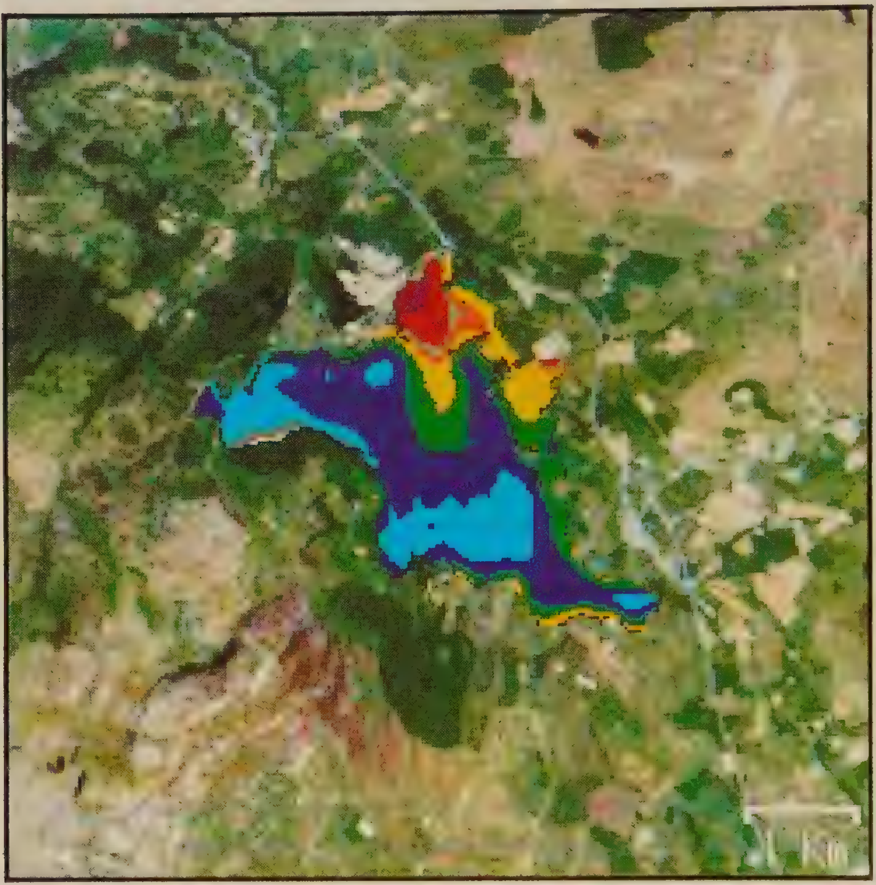
We have reported that there are many countries or regions which have not yet documented or created an inventory of their existing waterways or inland lakes, e.g. Shimang (1989) reports the problem in Nigeria and Vincke (1990) in Malawi. The latter author describes in some detail how the use of Landsat MSS and TM data, helped by extensive ground truthing, can facilitate an inventory of all lakes of over about 1 ha. Adeniyi (1988) reports similar plans for N.W. Nigeria. As well as the actual existence of surface water supplies, RS can give clues to variable water flow rates, e.g. Cheney and Rabanal (1984) report several methods of relevant hydrologic modelling and Blair Rains (1985) reminds us that areas having extensive forest cover removal are liable to have accentuated hydrological characteristics with a greater incidence of flash flooding.

Estimates of the extent of snow cover can help with predicting river water levels following Spring thaws, and marked seasonal variations in both lake and river levels have been monitored, even with the use of the comparatively poor resolution Meteosat instruments, e.g. in Figure 4.25 the purple indicates open water and the green is vegetation. (Finch 1990) shows recent advances in the ability to assess sub-surface water resources using TM images, especially in semi-arid environments where these supplies might be critical to the long-term sustainability of fish production ventures. Since a huge potential exists for fish production in very small ponds, Kapetsky and Caddy (1985) recommend the use of airborne sensors for detection of same, though skilled interpretation of SPOT HRV data will enable many small water bodies to be located.

4.7.4 Economic Production Functions Related to Distance Factors or Population Distributions.

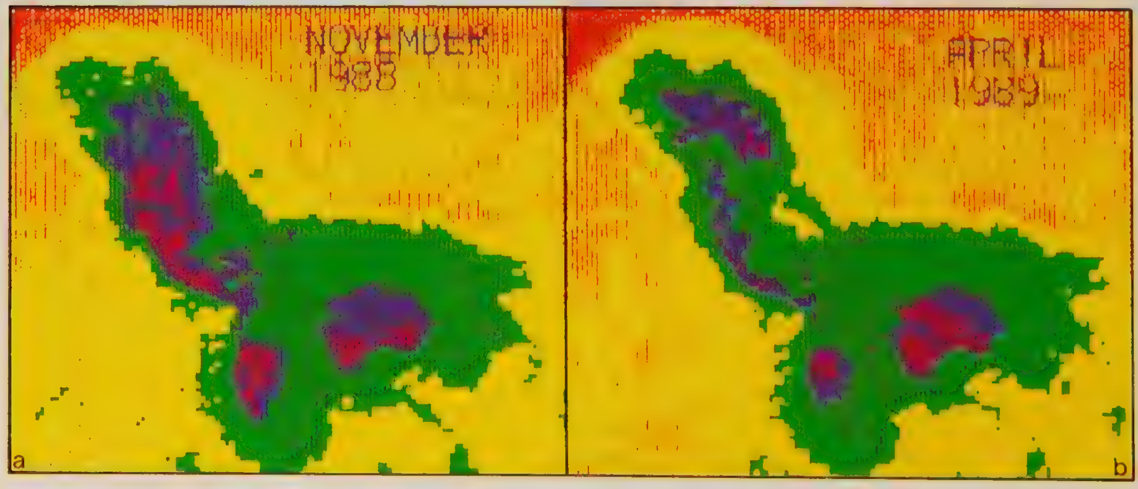
A large number of production functions are concerned with spatial distributions of a "man-made" social and economic environment, e.g. such factors as distance to the various markets, size of markets and the availability of various economic inputs. Since oblique remotely sensed images are analogous to maps, i.e. showing 2D distributions of spatially related objects at different scales, then they can be used in virtually the same way as maps. Once the scale has been determined, RS images can give direct information concerning distances, but they can only give inferred information on market size, input availability and land costs. SPOT HRV

Figure 4.24 Development of a Thermal Plume in a Lake in North Wales



Landsat TM image of Lake Trawsfynydd. The Lake is density sliced according to temperatures. The colours displayed show approximately 1°C differences. The warmest water is red, the coldest pale blue.

Figure 4.25 Density-Sliced Meteosat Images of Lake Chad in November and April



Density-sliced Meteosat images of Lake Chad, November 1988 and April 1989. Purple and blue tones indicate open water, green is vegetation, while yellow and orange tones indicate desert and semi-desert. The decrease in area of open water in the northwestern arm of the lake can be clearly seen.

data is ideal for mapping, and updating maps, at scales of >1:25 000. Most human developments of importance, e.g. roads and urban areas, can be discriminated and Iisaka and Hegedus (1982) have shown how, using appropriate models, reliable population estimates (inferring market size) can be made from Landsat MSS images. Once the digitizing of existing base maps has been accomplished for any given area, then updating can be continuously undertaken as more recent geometrically corrected imagery is acquired, and as automatic feature recognition techniques are applied and improved.

4.7.5 Climatic Factors

Many factors relating to weather and climate can, and are, being obtained and compiled from satellite RS imagery, and this data has been of help in compiling both short and long-term meteorological information. However, this data is of little direct use to prospective fish producers since, for the optimizing of production locations, the entrepreneur must be concerned with not only average long-term conditions but also known climatic extremes. This information would already be in existence for virtually all areas, i.e. at the only realistic scales which are very small. Short-term forecasting could be of value in indicating that a potentially hazardous event was imminent - one for which precautionary measures might be advisable, e.g. exceptionally strong winds or very heavy rain. Models are now being developed whereby future runs of particular weather conditions can be reliably inferred from present weather forecasts, e.g. of temperatures, wind directions or air pressure, though for the immediate future these are only likely to be successful for oceanic areas where there is spatially extensive uniformity of physical conditions.

4.7.6 Soils

Soil types can be inferred from RS images both directly and indirectly. Since natural vegetation types correlate strongly with soils, then the various vegetation categories will give a clue to the suitability of soils for pond construction. Soil type may also correlate with altitude, various climatic factors and with slope, and certain soil types will relate to areas of intensive crop production. Any indirect RS determination of soils must be carefully calibrated and substantiated by ground truthing. Several studies have shown that Landsat TM imagery is the most suitable for recording the very varied spectral reflectance characteristics of different soils, i.e. spectral signatures will vary with the amount of organic matter, mineral content, iron oxides present, moisture content, surface roughness as well as the percentage balance of sand, silt and clay. Post-soil classification evaluations of the predicted results show that soils can be categorized with almost total accuracy, and the area of each soil type can also be accurately estimated. Some confusion may be apparent between bare soils and areas of very low vegetation cover.

4.7.7 Relief

The ability of the SPOT HRV instrument to perform off-nadir viewing means that it is possible to obtain stereo-pairs of images, which in turn can be used for the plotting of contours, i.e. with the use of an Ortoster instrument. 50-metre contours can be plotted at a scale of 1:50 000. This is generally sufficient to determine whether slopes in a particular area would prove to be disadvantageous to aquaculture site location.

4.7.8 The Existence of Shelter for Cage Culture

The existence of shelter for sea cage culture will be a function of several factors, i.e. strength and direction of prevailing wind, length of fetch and the height of surrounding land. We have seen that relief is now able to be determined - this will give an indication as to potential shelter. The Seasat satellite, which was operational for a short time in 1978, proved the possibility of gaining very accurate measurements of wave height, i.e. with the RA instrument an accuracy to within 10 cms could be obtained, and another instrument on board, the SASS, measured surface wind speeds and direction in all weather conditions. From these instrument readings fairly accurate charts could be drawn up, which gave long-term average or extreme wave or wind conditions. The prospective ERS-1 satellite, will soon be able to continue to provide this data.

4.7.9 Bathymetry

Again knowledge of this function is important to cage culture. There are several methods of determining water depth in areas where it is relatively shallow (<20 m). Where water visibility is clear, the Landsat MSS instrument (using Band 4) can detect reflectance from the sea bed. At different depths, a different degree of brightness will be measured and bathymetric contours can then be drawn based on lines of equal brightness. In more turbid areas, then images using Band 4 reflectance captured on the Landsat TM sensor, can be preprocessed and then density-sliced to discriminate between water and sandbanks. The actual height of sub-surface sandbanks can be determined by using multiple images at different tidàl states, and, by using images captured over a period of time, sandbank dynamics can be calculated.

There are some other production functions which can be inferred from satellite imagery, e.g. monitoring of sea ice; monitoring of vegetation levels or biomass estimates in inland waters and the existence of coastal flora or habitat types such as mangroves, but space precludes an analysis of these. During the next decade it is anticipated that sensors with higher resolutions will become available, and not only will this improve upon the imagery available but it will also allow satellite platforms to be used to gain data on production functions which presently rely on airborne sensing.

4.8 The Acquisition of Remote Sensing Information

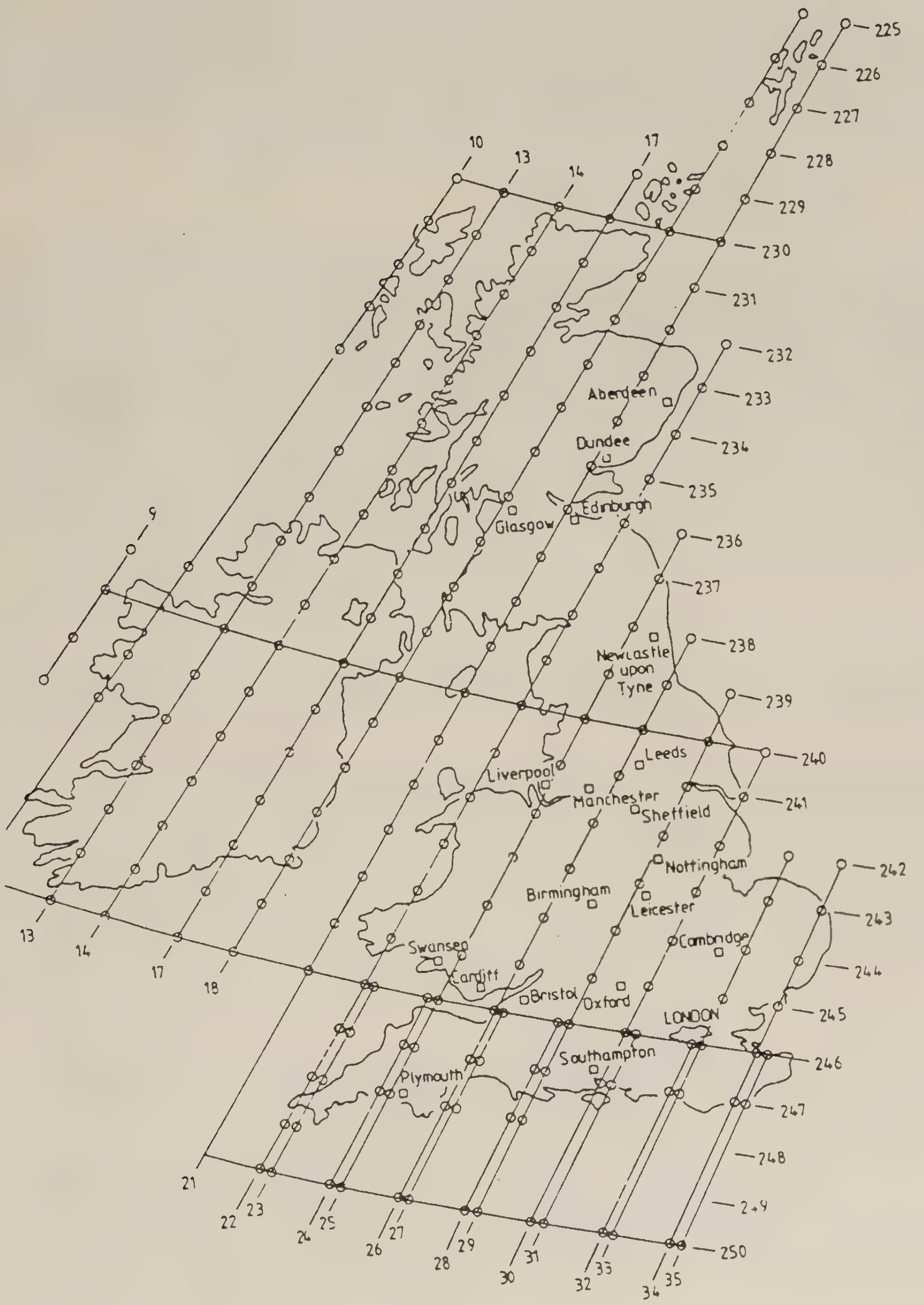
RS is a field of study which has not only generated a vast amount of new and usable data at an exponential rate, but it has spawned information about itself at a similar rate. Cordell and Nolte (1988b), in a study which was aimed at testing the feasibility of using RS to help in aquacultural location, noted - "The quantity of information (RS) to choose from is so large that it will tend to confuse and discourage customers who are unfamiliar with remotely sensed information." (p3.10). It has been our experience too, that those who are interested in RS will start to delve and very soon they will suffer from a surfeit of information. This being the case we need only briefly suggest where to start.

This section will endeavour to show firstly the range of products which are generally available from commercial companies and other organizations. These products will include both different forms of direct sensor output and various "spin-off" products. We will describe the sources of products, their availability, cost, etc., and finally we will look at the guidance and support facilities which will inevitably be required in any field as complex and internationalized as is RS.

4.8.1 Remotely Sensed Product Types

The wide range of RS products will have been created via the enactment of a large number of highly technological processes. Though we have discussed some of the data capture and data imaging processes, space precludes a discussion of those processes necessary to create the many different forms of products available from any one set of digital RS data. A number of satellite systems are producing different forms of output which spawn different products, but since the vast majority of output is presently, and easily, available from two main satellite series, Landsat and SPOT, we will concentrate mainly on these. The quality of data output is quite variable and therefore customers may stipulate minimum quality acceptance levels, maximum cloud cover acceptance and preferred times of year for an image. It is possible to obtain "quick-look" microfiche or photographic images before purchase to assess image quality. To order products the user should be familiar with the spatial referencing system appertaining to the satellite series. Referencing can be given by latitude and longitude coordinates, by SPOT reference grid nodes (see Figure 4.26), or for Landsat by a "World Reference System". Information about products from other sensor platforms can be obtained from some of the sources mentioned in section 4.8.2.

Figure 4.26 Part of the Referencing System Used in the SPOT Series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Dundee
Edinburgh
Glasgow
Newcastle upon Tyne
Leeds
Liverpool
Manchester
Sheffield
Nottingham
Birmingham
Leicester
Cambridge
Swansea
Cardiff
Bristol
Oxford
LONDON
Southampton
Plymouth

4.8.1.1 Digital data or computer compatible tapes (CCTs)

For SPOT images CCTs can be recorded at either 6250 or 1600 bits per inch (bpi). Given that the total volume of a SPOT scene (which is normally 60 x 60 kms but 60 x 80 kms for the maximum oblique viewing angle) is 27 to 100 Mbytes, then a single 6250 bpi tape can accommodate the entire scene. Two or three 1600 bpi tapes would be needed per scene depending on the scene data volume. Alphanumeric characters are coded by default in ASCII or optionally in EBCDIC, and files are organized according to "Band Interleaved by Line" mode or "Band Sequential" mode. Imagery on CCTs will have been pre-processed to one of six levels depending on customer choice.

CCTs showing Landsat imagery contain similar characteristics to SPOT for data volume and format. However, the levels of pre-processing will be different and more varied since data is derived from three sensors (MSS, RBV and TM) and there are three basic scene sizes available - full scene, quarter scene or a user defined map scene. A single Landsat full scene will cover about 9 times the area of a SPOT scene, though at a reduced resolution.

4.8.1.2 Photographic products

Both SPOT and Landsat images are available in black and white or colour formats, in film or as prints, and they may be at varying sizes which correspond to the scale of the image (see Tables 4.10 and 4.11). For both Landsat and SPOT special photographic products are available, e.g. for colour composites various specific bands from each Landsat sensor are used by default, but any combination of bands can be requested. SPOT special photographic products include various mosaics, colour composites, linear combinations of spectral bands, panchromatic photographs at 1:25 000 scale, stereoscopic images, "shift along track" or extended frame scenes, digital elevation models and orthophotos. Landsat also provide a similar range of special products. The range of photographic products available from the Kosmos series (via PRIRODA) is shown in Table 4.12.

Table 4.10 Availability of Landsat Photographic Products

Sensor	Nominal Image Size	Film	Paper	Scale
RBV Landsat 1,2 and MSS Landsat 1 to 5.	18.5cm (7.3ins)	X	X	1:1 000 000
	37.1cm (14.6ins)		X	1:500 000
	74.2cm (29.2ins)		X	1:250 000
RBV Landsat 3.	18.5cm (7.3ins)	X	X	1:500 000
	37.1cm (14.6ins)		X	1:250 000
	74.2cm (29.2ins)		X	1:125 000
TM Landsat 4 and 5.	18.5cm (7.3ins)	X	X	1:1 000 000
	37.1cm (14.6ins)		X	1:500 000
	74.2cm (29.2ins)		X	1:250 000

Table 4.11 **Availability of SPOT Photographic Products**

Scene	Nominal Image Size	Film	Paper	Scale	Processing Level
Whole	241cm x 241cm	X		1:400 000	1A,1B,S1,2,S2
	300cm x 350cm	X		1:400 000	2,S2
	482cm x 482cm	X	X	1:200 000	1A,1B,S1
	964cm x 964cm		X	1:100 000	1A,1B,S1
Quarter	241cm x 241cm	X		1:200 000	1A,1B,S1
	482cm x 482cm	X	X	1:100 000	1A,1B,S1
	964cm x 964cm		X	1:50 000	1A,1B,S1

4.8.2 Product Availability

RS products are available via a number of companies and organizations whose status varies from government level through to private commercial companies. With increasing volumes of data available, with rapidly rising costs in the space industry and with changing government priorities, a distinct trend towards a commercial outlook in the provision of data is obvious. Three major commercial companies are the primary source of all SPOT, Landsat and Kosmos imagery:

i) *SPOT Image*. This company, based in France, was formed in 1982 to handle all commercial distribution of SPOT imagery, to promote the system and to generate and process data. They have established a network of distribution points in over 20 countries. All SPOT scenes are archived and then referenced in a computerized data base called the "SPOT Image Catalogue" which can be accessed via telephone, telex and switched-packet international networks at any time. They also offer extensive guidance and support facilities. They have increased their business considerably since 1986, though they are never likely to cover satellite development costs.

ii) *EOSAT*. The Earth Observation Satellite Corporation was formed in 1985 as a joint venture by the Hughes Aircraft and the R.C.A. Corporations. It aims to promote future satellites in the Landsat and Omnistar series, develop new sensor systems, to promote and market Landsat imagery and to decrease government costs in RS. It presently receives a government subsidy of $19 million annually to cover Landsat 4 and 5 costs. It operates a network of receiving stations around the world and has its base at Lanham in Maryland. It holds over two million Landsat Images in a worldwide accessible digital archive and it also provides extensive user support facilities.

iii) *Soyuzkarta*. This company was set up by PRIRODA in 1987, both to help achieve economic accountability of the Russian RS industry and to accelerate efforts to increase sales of photographic products on a world-wide basis (Soyuzkarta-Kartex, 1987; Morrison and Bond, 1989). A vast geographic range of imagery is available, though it is all in photographic form and it would therefore need to be digitized before using in a GIS. Over 100 long-term contracts have already been made with "western" countries to supply imagery which uis supplied through a company called Central Trading Systems. There is a desire by PRIRODA to increase contacts with foreign firms to help economically and to acquire better technology and expertise.

These three companies have various agreements with other companies and organizations to supply RS imagery. These include:

Table 4.12 Kosmos RS Products Available With Prices (U.S.$) (from Morrison and Bond, 1989)

Survey camera and image type	Film positive	Film negative	Film negative in set with film positive	Contact print on paper	Paper print, 2X enlargement	Paper print, 4–5X enlargement
KFA-1000						
Scale and image format	1:270,000 30 X 30 cm	1:270,000 30 X 30 cm	1:270,000 30 X 30 cm	1:270,000 30 X 30 cm	1:130,000 4 parts, 30 X 30 cm	1:50,000 25 parts, 40 X 40 cm
Black and white	$1,180	$1,260	$1,360	$440	$660	$1,150
Color	$1,560	$1,650	$1,770	$550	$820	$1,400
MK-4						
Average scale[a] and image format	1:900,000 18 X 18 cm	1:900,000 18 X 18cm	1:900,000 18 X 18 cm	1:900,000 18 X 18 cm	1:500,000 36 X 36 cm	1:250,000 4 parts, 40 X 40 cm
Black and white, 1 band	$1,050	$1,110	$1,190	$210	$300	$440
Black and white, 3 bands	$2,520	$2,660	$2,860	$420	$600	$880
Color	$1,950	$2,070	$2,250	$700	$1,020	$1,600
Color synthesized[b]	$3,220	$3,470	$3,800	$750	$1,070	$1,600
KATE-200						
Scale and image format	1:1,350,000 18 X 18 cm	1:1,350,000 18 X 18 cm	1:1,350,000 18 X 18 cm	1:1,350,000 18 X 18 cm	1:700,000 36 X 36 cm	1:350,000 4 parts, 40 X 40 cm
Black and white, 1 band	$230	$250	$280	$100	$140	$220
Black and white, 3 bands	$550	$580	$630	$210	$310	$470
Color	$450	$480	$510	$200	$280	$420
Color synthesized[b]	$690	$750	$790	$235	$300	$450

[a] The image scale varies from 1:650,000 to 1:1,200,000 depending on the altitude of the orbit.

[b] Color synthesized film positives and negatives (transparencies) are supplied in a set with three black and white double-negatives in the different spectral zones from which the synthesized image is obtained.

a) EURIMAGE. This is a consortium of companies, formed in 1986, which have the right to market Landsat data on a commercial basis throughout Europe. They are based in Rome and work under the auspices of the European Space Agency (ESA).

b) EARTHNET. This is the ESA distribution network, based in Rome, which handles the European data from SEASAT, the Nimbus 7 CZCS, the HCMM, and from the NOAA and Meteosat satellites.

c) EROS. The Earth Resources Observation Systems Data Center is part of the U.S. Geological Survey, being located at Sioux Falls, South Dakota. It is responsible for archiving, reproducing and distributing the Landsat data held by the U.S.G.S., though current Landsat data is distributed through EOSAT. It therefore has a large selection of older images.

d) NESDIS. The National Environmental Satellite, Data and Information Service is part of NOAA in the U.S., and it provides a large range of RS products associated with meteorology, the ocean and the environment.

e) NCIC. The National Cartographic Information Center, in the U.S., also provides a range of map, photographic and satellite imagery.

f) NRSC. The National Remote Sensing Centre is situated at Farnborough in the U.K., where it is the main source for all satellite imagery. It provides an extensive user support system (see section 4.8.3).

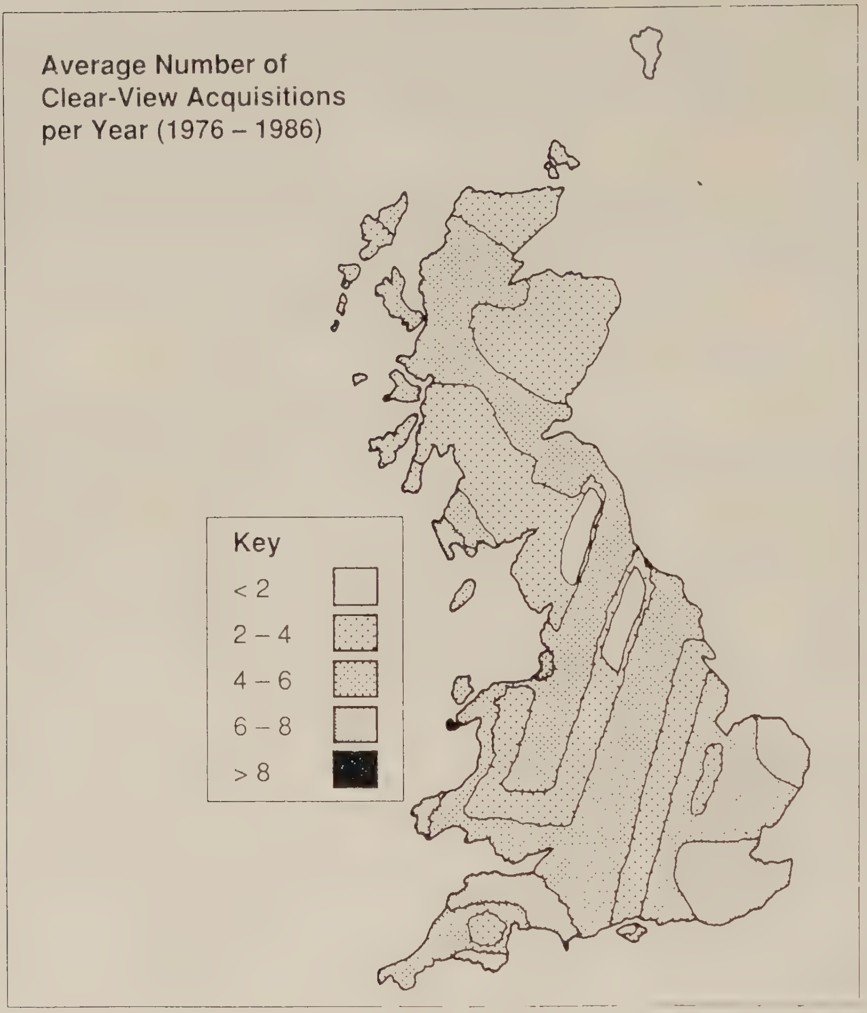
All these distributors have various forms of on-line, microfiche or microfilm data retrieval systems, many of which are accessible at other points or via computer telecommunication links. Computer listings of the data held are usually available. Although some of these companies and organizations purport to supply data obtained from Russian, Japanese or Indian satellite systems, in reality this may be hard to procure.

Spatial coverage of satellite imagery is now very comprehensive. Landsat TM and MSS data covers the whole world except a small exclusion zone over western China and the central Soviet Union. Having said this, there would be wide variations in the number of scenes available for any particular location. Figure 4.27 illustrates the amount of this variation over the comparatively small area of England, Wales and Scotland. The variations are mostly due to cloud cover problems, but they may also be a function of the satellite orbit return frequency and the degree of swath overlap, plus the systems performance of the spacecraft, e.g. systems performance of Landsat was very poor during 1983 and 1984 before Landsat 5 was in full operation.

The time taken to acquire imagery is usually two to three weeks, though by paying a high premium turn-around time can be as short as 48 hours. Prices for satellite imagery vary greatly according to products; an indication of 1989 Landsat prices is given in Table 4.13. SPOT prices are generally higher per km^2 of scene, especially for high resolution products and for those having undergone maximum pre-processing. Because of the desire to earn foreign exchange, prices for high resolution Soviet imagery are cheaper than either Landsat or SPOT, even after essential digitizing costs have been met.

It must be remembered that the costs shown in Table 4.13 are just for the data. Hardware and software costs for data manipulation are high and the costs of analyzing the data can also be high, especially if consultancy fees are necessary or if training costs are considered. It is likely that the commercial companies are charging prices which are too high for the research/scientific community, e.g. sufficient Landsat CCT images to cover the entire land area of the earth would be >$50 million. Having said this, if the costs of using RS imagery are calculated per km^2, then they may be considered to be very reasonable. In a recent study to test the cost-effectiveness of RS techniques for aquaculture site assessment (Chacon-Torres *et al*, 1988), for the Lake Patzcuaro area in Mexico, it was found that costs for digital MSS imagery plus necessary ground truthing were about 33% lower than for a conventional ground-based survey, and 38% lower than for a survey which combined aerial photography with ground-based methods. The authors did mention that these figures could be highly variable depending upon numerous extraneous factors.

Figure 4.27 Variations in Landsat Data Acquisition Over the U.K. for 1976 - 1986.


Average Number of Clear-View Acquisitions per Year (1976 – 1986)
Key
< 2
2 – 4
4 – 6
6 – 8
> 8

4.8.3 Guidance and Support Facilities

4.8.3.1 Support given by the major companies and organizations

In the last section we inferred that the major companies and organizations involved in RS offered a degree of guidance and support. Here we will look at this support in more detail and we will outline other avenues where help may be obtained. The range of guidance and support facilities will vary as a reflection of the primary aims of the company or organization. To exemplify this we will examine support given at three levels:

i) Commercial companies. Since their primary aim must be to maximize financial returns, their range of support will be limited. It will mostly fall under the broad notion of "marketing". Apart from selling the main CCT and photographic products they produce helpful material which maximizes the likelihood of selling more primary RS data. Examples of this would be:

Table 4.13 Selected Landsat Imagery Prices for 1990 (from EOSAT)

TM DIGITAL DECODED:		
Full scene	185 x 170 km	$4900
Quarter scene	100 x 100 km	3600
Map sheet	55.5 x 91.2 km	2500
TM DIGITAL MOVABLE SCENE (User defined):		
	100 x 100 km	$3200
	50 x 100 km (N-S x E-W)	2400
	100 x 50 km (N-S x E-W)	2400
TM COLOUR PRODUCTS (185 x 170 km):		
Positive transparency	1:1 000 000	$1800
Paper	1:1 000 000	1300
Paper	1:500 000	1400
Paper	1:250 000	1500
TM BLACK AND WHITE PRODUCTS (185 x 170 km):		
Positive transparency	1:1 000 000	$ 500
Paper	1:1 000 000	550
Paper	1:500 000	600
Paper	1:250 000	700
MSS DIGIOTAL PRODUCTS:		
	185 x 170 km	$1000
MSS COLOUR COMPOSITES (185 x 170 km):		
Positive transparency	1:1 000 000	$ 600
Paper	1:1 000 000	550
Paper	1:500 000	700
Paper	1:250 000	1000
MSS BLACK AND WHITE PRODUCTS (185 x 170 km):		
Positive transparency	1:1 000 000	$ 155
Paper	1:1 000 000	95
Paper	1:500 000	190
Paper	1:250 000	290

a) Computer listings of images available.
b) Directories or manuals containing product information about sources and uses of material.
c) Floppy discs containing imagery data or software programmes for data manipulation.
d) Posters and brochures aimed at company and product promotion.
e) Computerized data base catalogues or other product retrieval aids.

ii) *National Remote Sensing Organizations.* These will be government organizations whose raison d'être is to promote an "industry" in which much government investment may have been made. A much broader approach to promotion can be made because financial considerations are not paramount. As well as providing the support that commercial companies do, and acting as agents to distribute the products from the commercial companies, they may also:

a) Issue regular newsletters concerning the whole "industry".
b) Offer consultancy services to specialist users.
c) Carry out research aimed at broadening the use of RS.
d) Offer facilities such as film writing, image analysis or image processing at their premises.
e) Distribute a wide range of promotional materials such as posters, fact-sheets, slide sets, videos, product catalogues, etc.
f) Run various educational or training programmes.
g) Operate libraries with archive or browse facilities.
h) Operate travelling exhibitions geared to a range of venues.

iii) *The FAO Remote Sensing Centre (FAORSC).* Operating on a global scale, the organization's objective is to use space technology to help bring about self-reliance of developing countries. They offer many of the support facilities listed for commercial companies and for national organizations, but dealings are usually at a governmental level and a list of the type of support offered reflects this:

a) Advising countries on the suitability, availability, etc. of RS data, and on methods, techniques and equipment.
b) Conducting practical training courses at national or regional levels.
c) Developing RS centers and national RS networks.
d) Undertaking pilot studies to demonstrate the utility of RS.
e) Promoting RS technology and applications through technical publications and technical support.
f) Identifying and developing RS projects to help with resource assessment, management and exploitation.
g) Providing geographic data on the availability of RS imagery.
h) Promoting environmental monitoring by the use of RS.
i) Providing early warning systems on food security concerns.
j) Promoting international technical cooperation in space applications between member nations and international organizations.

4.8.3.2 Other sources of guidance and support

World-wide there are now a large number of learned and professional societies which may be related to RS in various ways. These societies propagate information and support by holding conferences and symposia, by issuing special publications, technical papers and conference proceedings and by organizing courses, workshops and regular meetings. World-wide there are also numerous university courses which are either completely devoted to RS or which RS forms a significant part of. For a select bibliography, which covers RS at a general or introductory level, we would recommend : Curran (1985), Lo (1986), Mather (1987), Hyatt (1988) and Drury (1990). Cordell and Nolte (1988a) provides a detailed practical summary, directed towards aquaculture, of how to acquire RS information. Finally, Table 4.14 offers a list of some available journals whose content is mostly devoted to RS.

4.9 Problems of Utilizing Remote Sensing Methodologies

Inherent in the introduction of any comparatively new, large-scale and complex technology there will be problems - indeed the very fact of making progress is achieved by overcoming problems. So in some senses, it could be argued, we should not be concerned with them.

However, since some authors have argued that RS has failed to live up to its proclaimed potential (Young and Green, 1987), and within the RS community it is freely acknowledged that its capabilities may have been oversold, then it is only reasonable to highlight a few of the major problems. Space again precludes a detailed discussion and some problems have previously been alluded to.

Table 4.14 Journals Which are Mostly Devoted to Remote Sensing

a) Arianespace.
b) Atlantic Canada Remote Sensing Newsletter.
c) Aviation Week and Space Technology.
d) EARSEL News.
e) Earth Observation Quarterly.
f) E.S.A. Journal.
g) European Space Report
h) Geocarto International.
i) Geoscience and Remote Sensing.
j) ISPRS Journal of Photogrammetry and Remote Sensing.
k) ITC Journal.
l) International Archives of Photogrammetry and Remote Sensing.
m) Int. Journal of Aerial and Space Imaging, Remote Sensing and Integrated Geographical Systems.
n) Int. Journal of Remote Sensing.
o) Journal of Geophysical Research.
p) Journal of IEEE Geosciences and Remote Sensing.
q) La Lettre du CNES.
r) Mapping Sciences and Remote Sensing.
s) Photogrammetric Engineering and Remote Sensing.
t) Remote Sensing in Canada.
u) Remote Sensing Letters.
v) Remote Sensing of Environment.
w) Remote Sensing Society Newsletter.
x) Space News.
y) Space Policy.

4.9.1 The Variable Amount of Accessible Data

We have briefly explained that data accessibility is variable spatially, i.e. within a comparatively short distance it may vary by a factor of five or more. This variability is caused mostly by cloud cover and temporal variations in the functioning of sensors. We should add here that certain climatic zones pose particular problems to RS, i.e. especially the humid tropics where cloud cover is frequently high, plus west-facing coasts in the mid to high latitudes where onshore prevailing winds cause high cloud cover, and those areas which have seasonal rainfall due to movements in the inter-tropical convergence zone. Some areas may lack data for other reasons, e.g. politically sensitive areas, areas beyond the receiving range of some satellite transmitters and high latitude areas.

4.9.2 The Necessity for Ground Truthing

We have seen that it is necessary to verify the imagery, i.e. by matching up various known classes of land cover with pixel values displayed on images for the given area. This is necessary since pixel values for any specific point will vary from day to day according to a number of extraneous factors. This means that RS use has to constantly consider this inconvenience in terms of cost, problems of accessibility and the necessity of ground truthing at approximately the same time as the satellite overpass.

4.9.3 Accessibility to Suitable Hardware

It is very clear that RS produces vast amounts of digital data and that whatever form this is used in expensive hardware will be required to process it. The more that the use of the data can be maximized, the more expensive will be the necessary hardware. The spatial areas and the types of programmes where RS techniques are likely to prove most valuable are also those which may be at a physical distance from any suitable hardware. Although data is beginning to be available in cheaper forms, e.g. floppy disks, and hardware will undoubtedly proliferate and fall in price, cost and accessibility will continue to make many potential RS using programmes non-viable.

4.9.4 Spatial Resolution

For many purposes airborne sensing still offers the highest resolution and the lowest price, and until resolutions get down to about the five meter size then RS imagery will continue to have its limitations. Although the technology exists to secure better resolution levels, there are political, cost and legal barriers to be overcome before it is generally available. Though the present SPOT resolution of 10 meters is valuable, there are many facets of the human landscape, especially in developing countries, which are not easily determined or cannot be detected at all. Though Wright (1988) has noted, with a degree of truth, that the present crude pixel size could be an advantage given that the data volume problem would be greatly exacerbated with a smaller pixel size, RS is likely to have far greater user acceptance and project applicability with an improvement in resolution.

4.9.5 Commercialization of RS Products

The increasing trend to commercialize RS output throws up a number of quite significant problems. Clearly products sold will need to have very stringent copyright regulations which themselves will need careful interpretation, e.g. who has the right to purchase individual scenes and can anyone else then purchase exactly the same scene? Agreements which must be carefully set up on a world-wide basis to operate product outlets or agencies, and this has led to a new and complex field of "space law". Allied to these commercial problems are those of where to fix prices - there is the divergence in the need to recover large costs yet the need to sell data, often to organizations in the less developed world who can ill afford expensive imagery.

4.9.6 Long-Term Planning and Payload Uncertainty

Most potential users of RS require assured access to imagery over a long temporal period, even if it is simply to justify the necessary hardware and software expenses for one project. A major problem that the industry faces is, what has been called elsewhere, "planning blight". Virtually all satellite launches have suffered from uncertainty in scheduling and payloads, with most programmes being significantly behind schedule. For example, ERS-1 will have suffered at least a three-year launch delay, and Landsat 6 was supposed to have carried a SEA-WIFS sensor but this has been abandoned. Delays have been caused by a lack of funding, technological problems, major disasters such as Challenger, etc. It is difficult to sell a technology which has such an unreliable track record, and any short or long-term planning is at the best vague.

Whilst there are many other minor problems, e.g. delays in data acquisition, lack of trained personnel, etc., the application of RS to aquaculture and inland fisheries does not in fact suffer problems as much as the application would to many other enterprises or fields. This is because, except for some of the water qualitative parameters, production functions controlling fish production do not require real-time or regular repeats of imagery, and given that RS can only really help location optimizing at the macro scale, then resolution is also not a problem.

4.10 Some Relevant Observations on the Future of Remote Sensing

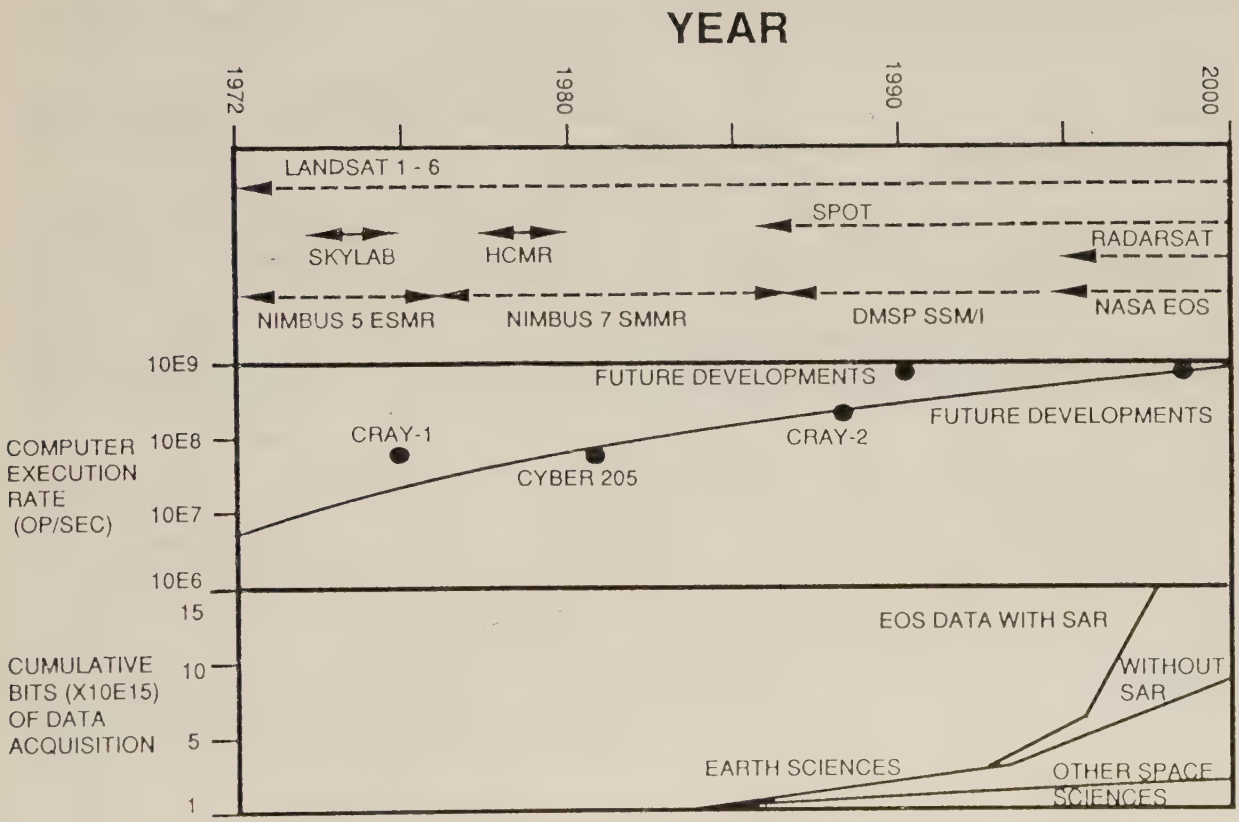
We have no intention here of cataloguing future RS satellite missions - for those interested we recommend Voute (1986) and Petterson (1989). Instead we wish to mention a few observations which might be particularly pertinent to readers of this study.

Though there are many problems and uncertainties in the RS domain, we are convinced there is a very healthy future for the "industry". This belief is based on a number of factors:

a) The large number of planned and committed satellite launchings.
b) The blossoming number of fields in which RS is applicable.
c) The increasing ease in which RS can be integrated into GIS programs (see Chapter 6).
d) The human competitive desire to overcome the immediate RS problems.
e) The likelihood of defence funding being switched to alternative but parallel schemes.
f) The vital role that RS is likely to play in the growing environmental awareness scene.

Something of this growth scenario is encapsulated in Figure 4.28.

Figure 4.28 Future Developments in Computer Power, Data Acquisition and Earth Observation Sensors (from NASA, 1988)



Some of the important trends which we see occurring are:

i) New types of sensor platforms are being planned, e.g. Omnistar is being developed by EOSAT. This is a flexible platform which is designed to be serviceable from the space shuttle. It therefore allows for the "in-orbiting" update of new sensors, for a variety of sensor systems to be carried and it will ensure the RS user a continuity of data flow.

ii) Whereas previous experimental work was carried out using normal polar orbiting satellites, this is now more likely to take place aboard the earth shuttle, aboard manned space stations or even in ground-based facilities.

iii) There are a number of new countries entering the satellite RS field in the immediate future, e.g. Canada, Brazil, China, Indonesia/Netherlands. This is likely to lead to a greater access to data since these countries will wish to make a return on their expensive investment. Much of this data is likely to concentrate on areas where aquaculture and inland fisheries has a huge growth potential.

iv) As an increasing amount of data becomes accessible it creates the ability to monitor temporal changes via time-series modelling. This might be important to production functions which relate to water quality and land use.

v) By the mid-1990s the cloud cover problem will be substantially overcome because three forthcoming satellite series are planned which carry SAR sensors, i.e. operating in the microwave portion of the spectrum, thus allowing for weather independent high resolution imagery. This will greatly benefit the humid tropical areas where aquaculture and inland fisheries has the greatest potential future.

vi) There is likely to be closer cooperation between countries to launch joint satellite ventures. This will be done for cost cutting and political motives.

vii) There are likely to be more user-oriented imagery capture systems, especially operated by the commercial companies such as SPOT Image or EOSAT. This allows the satellites to be programmed to individual user requirements.

viii) There is certain to be a lot of attention given to the problem of: "When is a satellite commercially viable?" Unless this problem can be satisfactorily solved then future pricing, and the actual supply of products, will remain uncertain.

ix) To considerably broaden the potential use of RS data, there will be an urgent need to make image processing software more available and affordable for microcomputers.

CHAPTER 5 - TRADITIONAL MAPPING AS AN AID TO SPATIAL DECISION-MAKING

5.1 Introduction

Having set out the ways in which data can be collected for use in the spatial decision-making exercise, we are in a position to see how the data can be used. Referring back to Figure 1.3 (p.6), it can be seen that raw data is either used as the basis of drawing up various forms of maps, or it can be entered directly into the GIS. This chapter will be concerned with the use of maps as the input to optimizing spatial decisions on aquaculture and inland fisheries. These maps can either be used as they are, or more usefully they can be digitized and can represent the major input to GIS.

Our account about maps needs to be prefaced by a few general cautionary remarks. In performing any task which attempts to utilize and combine a great deal of disparate data in order to produce a series of maps which will be of use in satisfying a single, rather specific, objective - in this case seeking locations for given enterprises in given areas at the present time, or in the near future, then there are bound to be many limitations which must be borne in mind when interpreting the results, e.g.:

a) Factors relating to scale - the data sources will have varying scales and the optimum scale to be working at will vary from case to case.

b) Amount of detail - all source material will have been collected showing a different degree of detail, with varying degrees of accuracy and generalizations and having certain simplifying assumptions.

c) Dating differences - rarely will combinations of data all have the same date and the subjects being dated will "date" at different rates.

d) Degree of applicability - much data will have been purposefully collected; other sources might be "proxy" data, i.e. the best available.

e) Availability - all data varies greatly in its cost, its diffusion level (how well it is known) and how easy it is to acquire.

Each country or region will have its own spatial inventory processes, preferences and standards and the interested reader ought to find these out to his or her own satisfaction.

This chapter will comprise of three main sections. Firstly, we will examine the fundamental type of map, a topographic map. From this type virtually all other maps can be successfully produced. The main sub-category of maps produced are thematic maps - these will be looked at both generally and with regard to the main production functions. Finally, what may be called "derived" maps are considered. These represent a type of "proxy" map - one that has been specifically produced for a particular purpose, it usually having been created from a variety of data sources and it is usually only made for a "one-off" situation. It is important to cover this area in some detail because it is the logic behind the construction of the derived maps which will be crucial to the success of GIS, i.e. since the quality of the output gained must principally be related to the quality of the data inputs.

5.2 Topographic Maps

These are general purpose maps whose main function is to portray and identify features of the Earth as faithfully as possible having regard to the imposition set by scale. They are the typical product of most national mapping agencies, and are usually produced in series which consist of all the necessary sheets to cover one region at one scale. Many different scales may be produced and these are typically classified as follows:

Large scale	1:1 250 to 1:25 000.
Medium scale	>1:25 000 to 1:200 000.
Small scale	>1:200 000.

Topographic maps usually form the basis of thematic maps; indeed many thematic maps are simply overlays superimposed on a topographic background. Examples of small-, medium- and large-scale topographic maps are shown in Figure 5.1. All topographic maps have clearly identified keys, scales, direction indicators and a grid/coordinate system, and some series may be produced in colour.

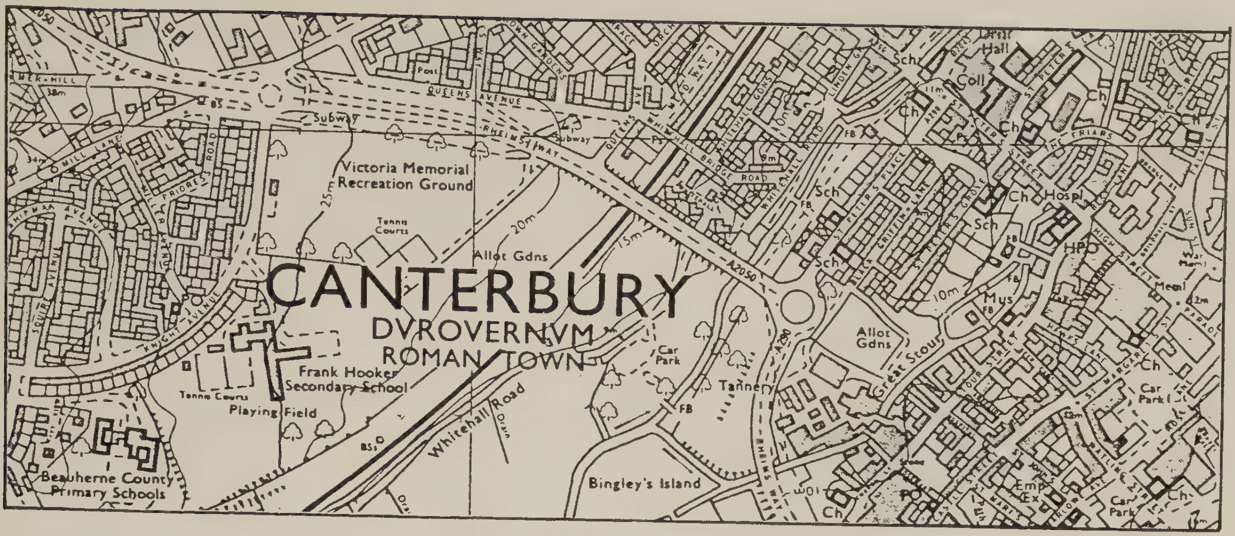
Features shown on topographic maps will vary with scale. On smaller scale maps the main features shown are: rivers, lakes, coastlines, altitude (usually in contours), settlements, transport routes, various political boundaries, sometimes forest or woodland plus certain prominent natural or human features. It is impractical to list all the features shown on larger scale topographic maps, but Figure 5.2 illustrates a typical key to such a map.

Despite the obvious high quality of most topographic maps, there are several problems associated with their use. The rate of topographic mapping coverage varies greatly worldwide. As an example of this Bohme (1988) notes that the rates of mapping by continent at the 1:25 000 scale in 1983 were:

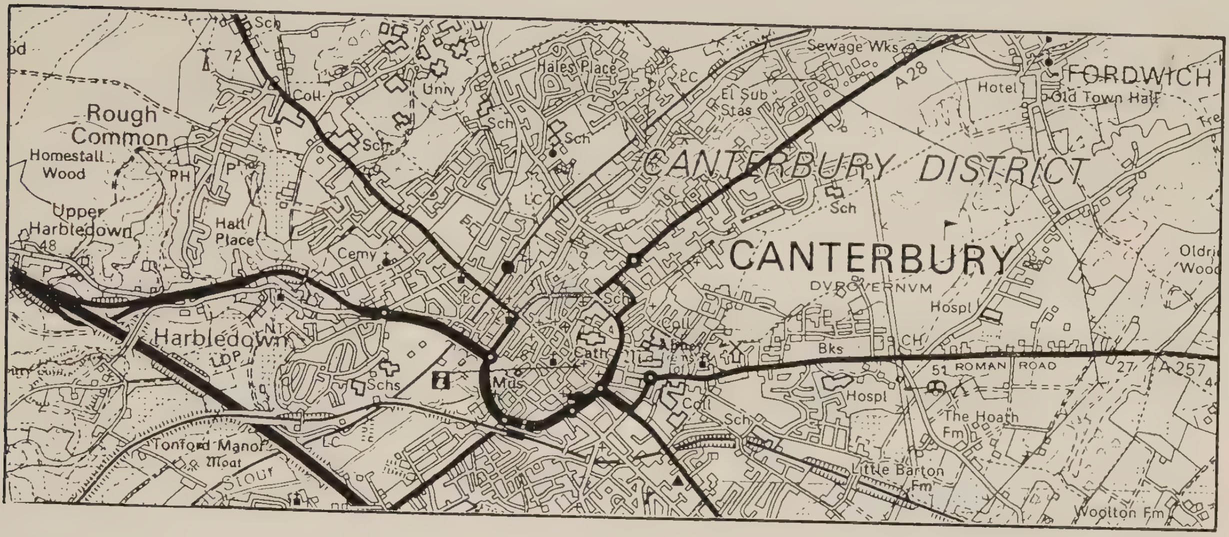
Africa	2.4% of land area.
N. America	33.8%
S. America	9.5%
Europe	90.9%
U.S.S.R.	5.0%
Asia	11.0%
Australasia	13.3%

The accuracy of some of this data might be questionable since Yashchenko (1990) states that the entire U.S.S.R. is now mapped at a 1:25 000 scale. About 80% of the world has been mapped at a 1:250 000 scale, though at this scale the figure is 100% for Europe, U.S.S.R. and Australia. Butler *et al* (1987) notes that about 42% of the world is mapped at the 1:50 000 scale. This low level of mapping is critical for developmental planning since mapping scales from 1:50 000 to 1:100 000 are optimal for economic planning and general location decisions. Table 5.1, compiled from Parry and Perkins (1987), gives a general indication of smaller scale topographic map availability for West Africa, though it does not indicate the age of maps. Very few recent larger scale topographic maps exist here. Since current rates of mapping or map revision are so low, it is unlikely that the target of complete world coverage at 1:50 000 or 1;100 000 scales will be achieved by the year 2000 as hoped (Bohme, 1988).

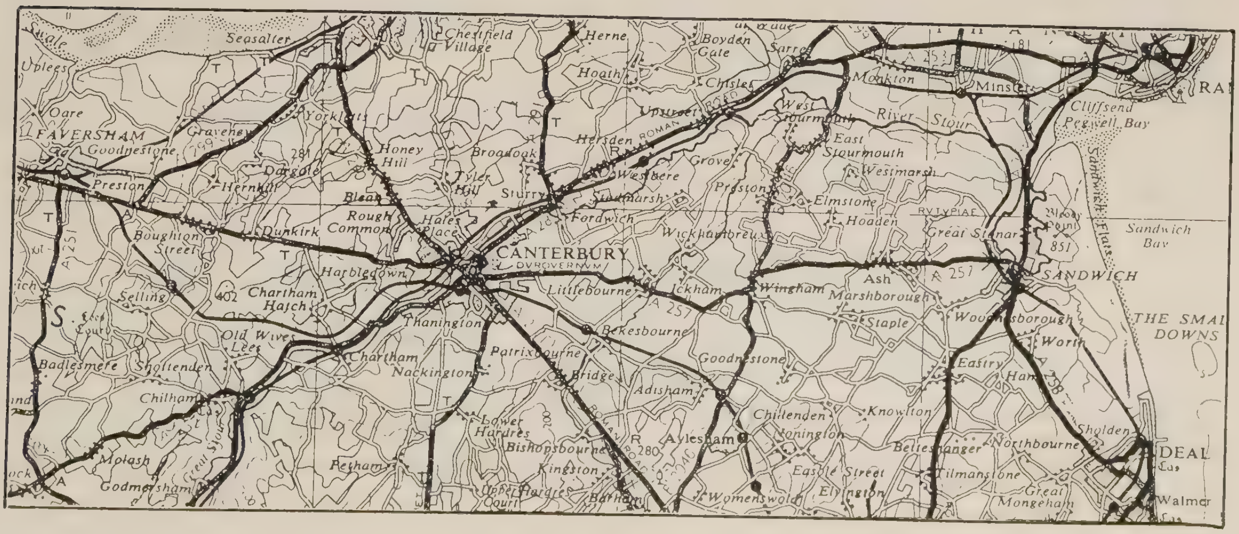
Figure 5.1 Examples of Large, Medium and Small Scale Topographic Maps


CANTERBURY
DVROVERNVM
ROMAN TOWN
Victoria Memorial Recreation Ground
Tennis Courts
Allot Gdns
Frank Hooker Secondary School
Playing Field
Beauherne County Primary Schools
Whitehall Road
Bingley's Island
Tannery
Car Park
Queens Avenue
Rheims Way
Subway
Great Stour
Sch
Ch
Coll
Hospl
Mus
A2050
25m
20m
15m
10m

(a) 1:10 000

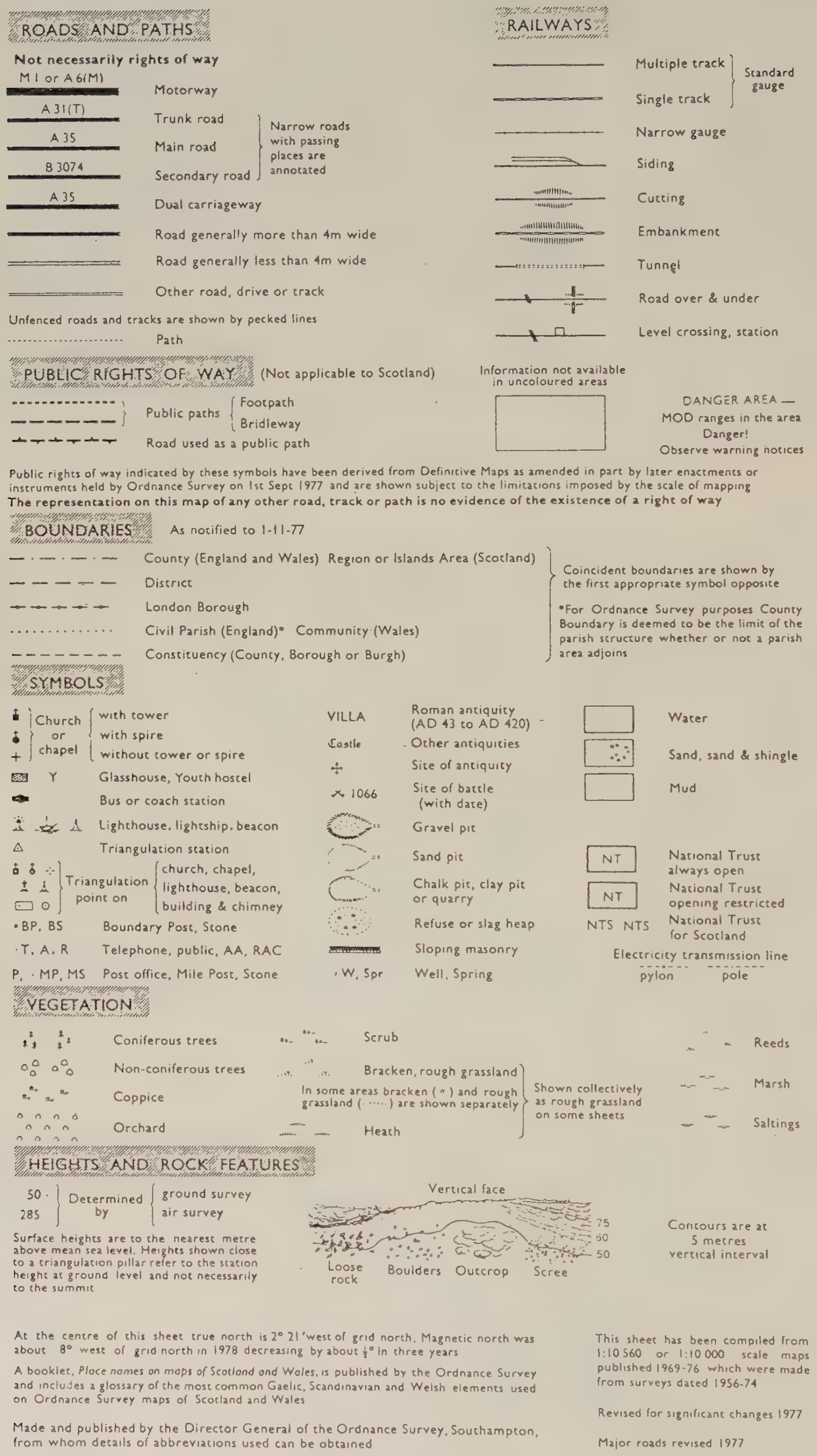

CANTERBURY DISTRICT
CANTERBURY
DVROVERNVM
FORDWICH
Old Town Hall
Hotel
Sewage Wks
Hales Place
Univ
Rough Common
Homestall Wood
Upper Harbledown
Hall Place
Harbledown
Tonford Manor
Moat
Stour
Cemy
Cath
Mus
Schs
Hospl
Bks
ROMAN ROAD
A28
A257
The Hoath Fm
Little Barton Fm
Woolton Fm
Oldridge Wood
El Sub Stas

(b) 1:50 000


CANTERBURY
DVROVERNVM
FAVERSHAM
SANDWICH
DEAL
Walmer
Seasalter
Chestfield Village
Herne
Hoath
Boyden Gate
Sarre
Chislet
Monkton
Minster
Cliffsend
Pegwell Bay
Sandwich Bay
THE SMALL DOWNS
River Stour
West Stourmouth
East Stourmouth
Westmarsh
Elmstone
Hoaden
Great Stonar
Preston
Grove
Upstreet
Hersden
Westbere
Sturry
Fordwich
Broad Oak
Tyler Hill
Honey Hill
Yorkletts
Graveney
Goodnestone
Hernhill
Dargate
Blean
Rough Common
Hales Place
Dunkirk
Boughton Street
Harbledown
Chartham Hatch
Selling
Old Wives Lees
Chartham
Thanington
Nackington
Littlebourne
Ickham
Wickhambreux
Wingham
Ash
Marshborough
Staple
Woodnesborough
Worth
Eastry
Ham
Bekesbourne
Patrixbourne
Bridge
Adisham
Goodnestone
Chillenden
Nonington
Knowlton
Betteshanger
Northbourne
Sholden
Tilmanstone
Great Mongeham
Aylesham
Lower Hardres
Bishopsbourne
Kingston
Barham
Upper Hardres Court
Petham
Womenswold
Eastle Street
Elvington
Badlesmere
Shottenden
Chilham
Molash
Godmersham
A 257
A 253
A 251
A 2

(c) 1:250 000

Figure 5.2 Example of a Key to a 1:25 000 Scale Topographic Map



ROADS AND PATHS

Not necessarily rights of way

M 1 or A 6(M) Motorway

A 31(T) Trunk road

A 35 Main road

B 3074 Secondary road

Narrow roads with passing places are annotated

A 35 Dual carriageway

Road generally more than 4m wide

Road generally less than 4m wide

Other road, drive or track

Unfenced roads and tracks are shown by pecked lines

Path

PUBLIC RIGHTS OF WAY (Not applicable to Scotland)

Public paths: Footpath, Bridleway

Road used as a public path

Public rights of way indicated by these symbols have been derived from Definitive Maps as amended in part by later enactments or instruments held by Ordnance Survey on 1st Sept 1977 and are shown subject to the limitations imposed by the scale of mapping

The representation on this map of any other road, track or path is no evidence of the existence of a right of way

RAILWAYS

Multiple track, Single track: Standard gauge

Narrow gauge

Siding

Cutting

Embankment

Tunnel

Road over & under

Level crossing, station

Information not available in uncoloured areas

DANGER AREA — MOD ranges in the area
Danger!
Observe warning notices

BOUNDARIES As notified to 1-11-77

County (England and Wales) Region or Islands Area (Scotland)

District

London Borough

Civil Parish (England)* Community (Wales)

Constituency (County, Borough or Burgh)

Coincident boundaries are shown by the first appropriate symbol opposite

*For Ordnance Survey purposes County Boundary is deemed to be the limit of the parish structure whether or not a parish area adjoins

SYMBOLS

Church or chapel: with tower, with spire, without tower or spire

Y Glasshouse, Youth hostel

Bus or coach station

Lighthouse, lightship, beacon

Triangulation station

Triangulation point on church, chapel, lighthouse, beacon, building & chimney

• BP, BS Boundary Post, Stone

• T, A, R Telephone, public, AA, RAC

P, • MP, MS Post office, Mile Post, Stone

VILLA Roman antiquity (AD 43 to AD 420)

Castle Other antiquities

Site of antiquity

1066 Site of battle (with date)

Gravel pit

Sand pit

Chalk pit, clay pit or quarry

Refuse or slag heap

Sloping masonry

• W, Spr Well, Spring

Water

Sand, sand & shingle

Mud

NT National Trust always open

NT National Trust opening restricted

NTS NTS National Trust for Scotland

Electricity transmission line: pylon, pole

VEGETATION

Coniferous trees

Non-coniferous trees

Coppice

Orchard

Scrub

Bracken, rough grassland

In some areas bracken ( ) and rough grassland (······) are shown separately

Heath

Shown collectively as rough grassland on some sheets

Reeds

Marsh

Saltings

HEIGHTS AND ROCK FEATURES

50 · 285 Determined by ground survey, air survey

Surface heights are to the nearest metre above mean sea level. Heights shown close to a triangulation pillar refer to the station height at ground level and not necessarily to the summit

Vertical face

Loose rock, Boulders, Outcrop, Scree

75, 60, 50

Contours are at 5 metres vertical interval

At the centre of this sheet true north is 2° 21′ west of grid north. Magnetic north was about 8° west of grid north in 1978 decreasing by about ½° in three years

A booklet, *Place names on maps of Scotland and Wales*, is published by the Ordnance Survey and includes a glossary of the most common Gaelic, Scandinavian and Welsh elements used on Ordnance Survey maps of Scotland and Wales

Made and published by the Director General of the Ordnance Survey, Southampton, from whom details of abbreviations used can be obtained

This sheet has been compiled from 1:10 560 or 1:10 000 scale maps published 1969-76 which were made from surveys dated 1956-74

Revised for significant changes 1977

Major roads revised 1977

Table 5.1 Smaller Scale Topographic Map Availability in West Africa

	Map Scale			
Country	1:2 000 000	1:500 000	1:200 000	1:100 000
West Africa	X	Xa		
Benin		Xb	X	
Burkina Faso			X	
Gambia			Xc	
Ghana	Xd		Xc	
Guinea			X	
Guinea Bissau		X		
Ivory Coast	Xe	X	X	
Liberia	Xf		Xc	
Mali			X	
Niger			X	
Nigeria			Xca	X
Senegal			X	
Sierra Leone		X	Xc	
Togo			X	

a = partially mapped
b = 1:600 000
c = 1:250 000
d = 1:1 250 000
e = 1:1 000 000
f = 1:1 350 000

There are other problems related to map revision, accuracy and access. According to Bohme (1988), the revision of dominantly rural area sheets ought to occur at about 20-year intervals - in urban areas even a five-year cycle of revision could be inadequate. Needless to say these targets are rarely met and in many areas currently available sheets may be more than 30 years old. Maling (1989) has detailed the problem of both general standards of topographic mapping accuracy, and the variability in accuracy between different maps and RS image sources. In many parts of the world actual access to larger scale topographic maps is either impossible (for security reasons) or special permission must be sought, e.g. in Thailand, in many "Eastern bloc" countries and in ex-French colonies in West Africa (Parry and Perkins, 1987). A specific problem relating to aquaculture and inland fisheries is that the detail shown on inland water sources is frequently suspect. This relates primarily to water courses which may be intermittent or various water bodies whose spatial extent fluctuates seasonally (Anderson, 1989).

Topographic maps have been used, or could be used, to determine the spatial incidence of the following production functions associated with aquaculture or inland fisheries:

a) *Transport Accessibility.* At the medium scale all main and secondary road routes would be shown, and at the 1:25 000 to 1:50 000 scales most access roads are also shown. Rail, shipping, ferry, airport and bridging point data is mostly available if necessary. Kapetsky (1989) reports using 1:190 080 scale topographic maps for identifying roads in Johore, and Kapetsky *et al* (1987) use a 1:500 000 map to identify transportation networks in Costa Rica. Meaden (1986) used 1:250 000 Ordnance Survey maps to identify spatial variations in the density of the road network in England and Wales, by classes of road (see section 5.4.6).

b) *Market Accessibility.* Again the road network can give a clear indication of the relative accessibility of the various market outlets, including the potential for "farm gate" sales. Larger scale topographic maps give an indication of the extent of built-up areas, and the distribution of and density of the settlement pattern shown will give an indication of retail market size.

c) *Relief (Topography).* Large- and medium-scale topographic maps have a contour interval usually in the range of 5 to 50 meters. This can give an adequate indication of adverse slopes, i.e. the closeness of contours. Areas of marsh, artificial drainage or excessively flat land can be easily identified. For specific site selection large-scale topographic maps would be essential.

d) Other spatial variations in production functions which could be identified from topographical maps would be:

i) How close sites were to the head-waters of a river system, i.e. to reduce disease and pollution risks - but decreasing water quantity advantages.
ii) The availability of shelter for cage culture.
iii) The extent of inland bodies of water.

Additional to these uses, IFREMER (Institute for the Exploitation of the Sea) have used large-scale topographic maps more generally to survey and list all potential aquaculture sites around the coast of France (Girin, 1989), and Cordell and Nolte (1988b) used medium-scale topographic maps for initial area analysis to determine likely oyster culture sites in southern Alaska.

5.3 Thematic Maps

As maps have become increasingly complex, sub-sets of the original information have been more frequently displayed. These make up special purpose, or distribution or thematic maps. They may be drawn to show an almost limitless variety of selected spatially distributed features and their "...aim is the graphic representation of spatial patterns and relationships, in-so-far as these can be related to geographical space and transformed into cartographic symbols." (Lehmann and Ogrissek, 1988. p.85).

In order to get proportionality and direction correct, thematic maps are frequently based on topographic maps (or bathymetric charts) and indeed much of the topographic detail and labels may be retained. Additional data for compiling the thematic map may be derived from any of the sources discussed in Chapter 3.

Most thematic maps will be concerned with a single theme, though any individual map may show various sub-categories of that selected theme. In order to purposefully concentrate on any theme, thematic maps may abandon their spatial accuracy - these maps are then called cartograms and they frequently illustrate transport routeways such as airline routes, underground railway networks, etc.

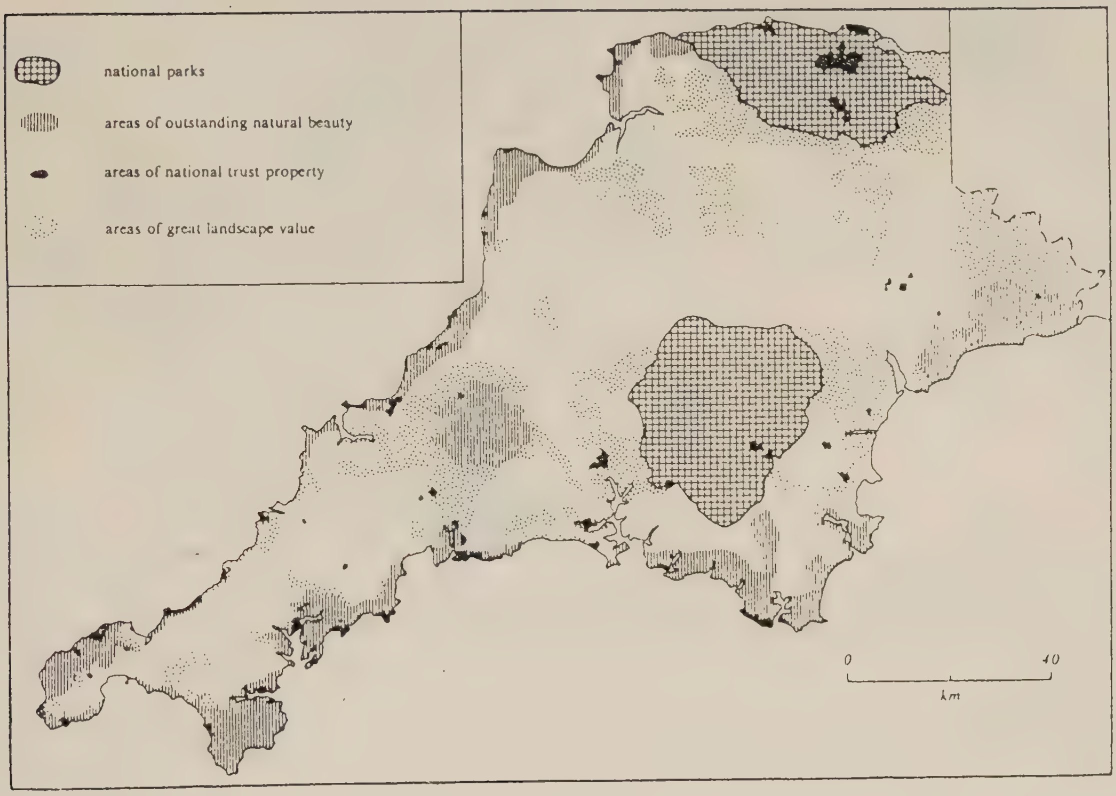
Because of the large range of subjects covered, and the fact that there is an increasing tendency towards computer-generated thematic maps, this type of mapping is growing at a very rapid rate, and their importance to GIS is increasingly being recognized (Bird, 1989). Many thematic maps are available for purchase "off-the-shelf" but by far the greatest number would have been purposely drawn to fulfil specific aims, e.g. for inclusion in a research study, to illustrate a particular area for inclusion in a publication or to help with some form of planning project. There is a rapid growth in the production of Thematic Atlases. These usually cover individual topics (themes) or show a variety of themes related to particular areas or countries.

5.3.1 Types of Thematic Maps

There has been no universal agreement on a classification of thematic maps, probably because the possibilities and complexities are almost infinite. However, it is realistic to briefly describe those major types which are easily identifiable:

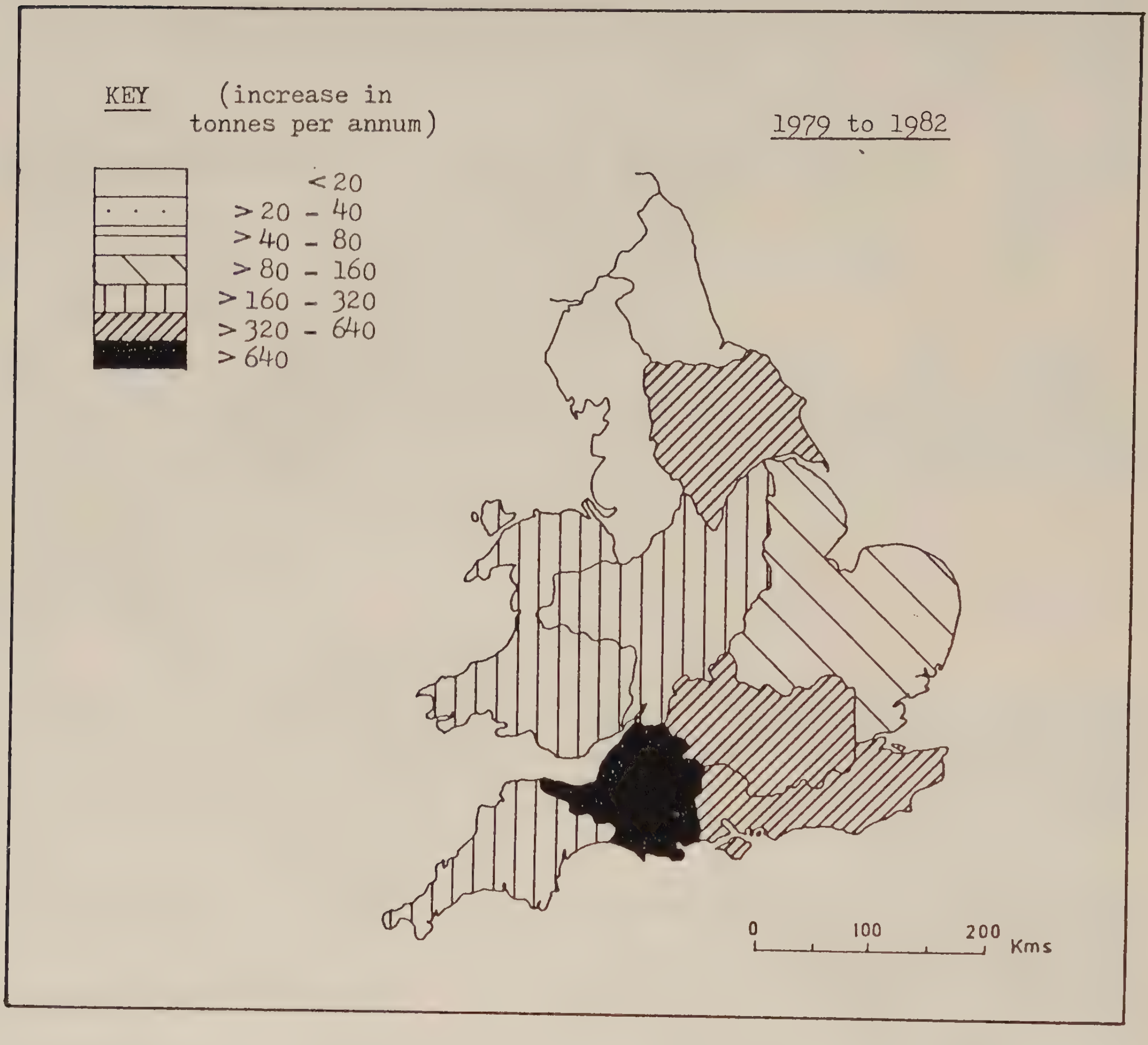
a) *Chorochromatic.* These show non-quantitative surface distributions of any feature, i.e. they simply portray the presence or absence of a particular characteristic over a given area (Figure 5.3). Whatever theme they are mapping can be sub-divided into various categories, e.g. as does a soil or geological map. The area under each particular use is either coloured or shaded in, and hence the name "colour patch" map is sometimes used.

Figure 5.3 Chorochromatic Map Showing Land Conservation Areas in S.W. England


national parks
areas of outstanding natural beauty
areas of national trust property
areas of great landscape value
0
40
km

b) *Choropleth.* These are maps which depict average values per unit of area over some administrative region for which statistics are available, such as density of population or a yield per unit area of land (Figure 5.4). To construct a choropleth map, the figures for each aerial unit must be calculated and, dependent upon the number of classes into which the map is being divided, class boundaries are established. These boundaries are themselves dependent upon the dispersion of the figures to be plotted. Colours or shadings should go from dark (highest density or number) to light (lowest density or number). The value of these maps is greatly dependent upon the number, size and shape of the aerial units, the number of classes chosen and the manner in which quantitative class boundaries are derived.

Figure 5.4 Choropleth Map Showing Changes in Table Trout Production in England and Wales

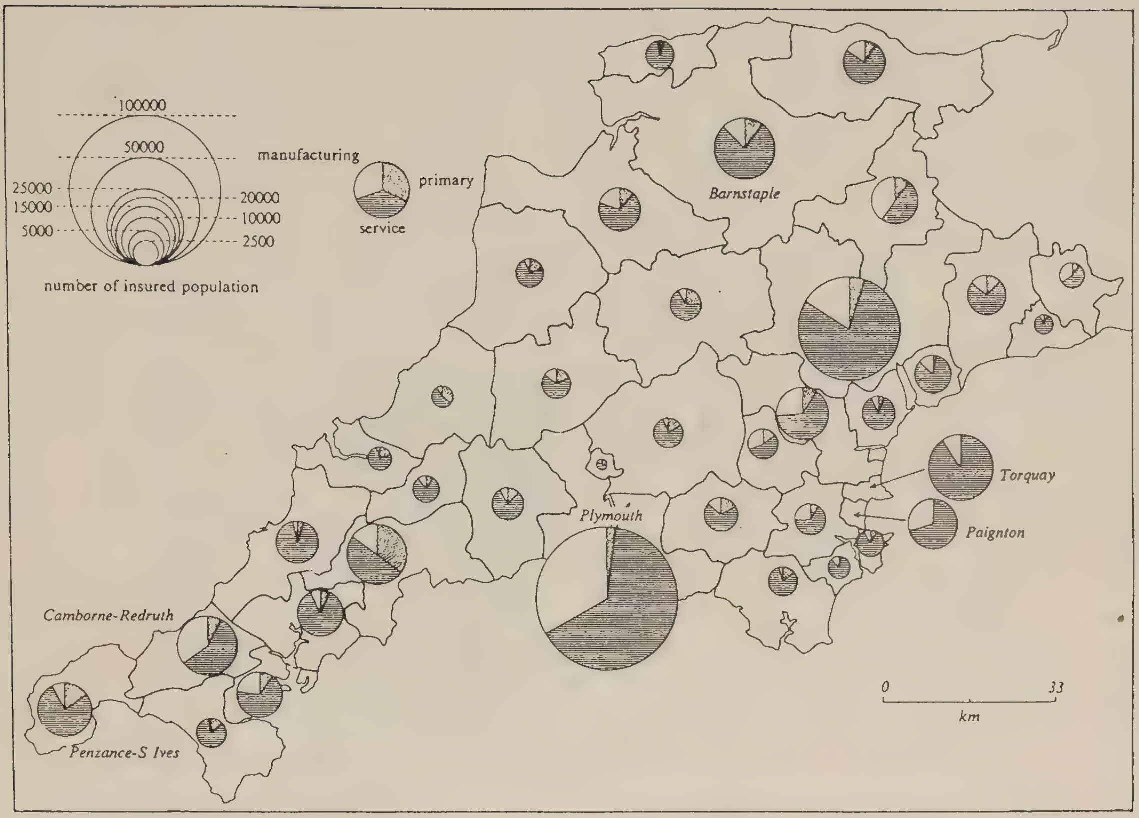

KEY (increase in tonnes per annum)
< 20
> 20 - 40
> 40 - 80
> 80 - 160
> 160 - 320
> 320 - 640
> 640
1979 to 1982
0
100
200
Kms

There are a wide number of variations on the choropleth map - the main ones are:

i) Dot maps - here the "shading" is carried out by means of placing dots within each aerial unit, so that the number of dots corresponds to the numbers being plotted.

ii) Volumetric symbols - these are drawn such that their area is proportional to the quantity that they represent. The symbols may usefully be subdivided so as to give additional quantitative information (Figure 5.5).

Figure 5.5 Volumetric Divided Circles Showing the Employment Structure of S.W. England

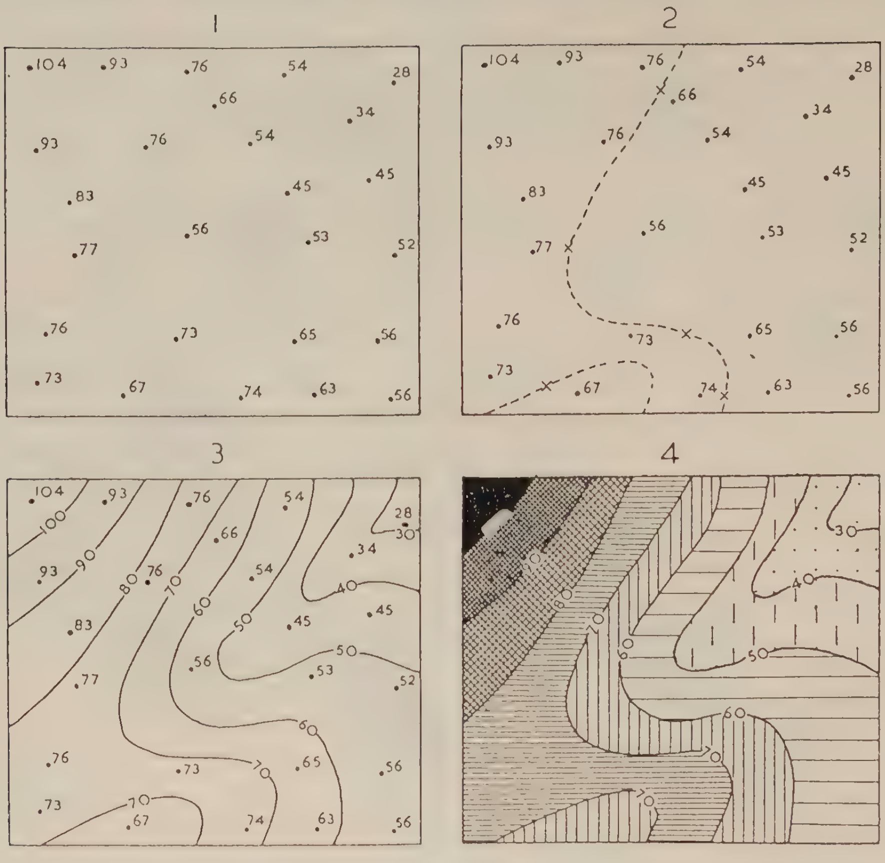

100000
50000
25000
15000
5000
20000
10000
2500
manufacturing
primary
service
number of insured population
Barnstaple
Torquay
Paignton
Plymouth
Camborne-Redruth
Penzance-S Ives
0
33
km

iii) Located Histograms or bars - these maps are similar to volumetric symbols but the symbols are replaced by sets of quantitative bars or histograms which are appropriately scaled and located.

c) *Isopleth.* The bases of these maps are the plotting of values for a particular surface, which are then used as interpolation points for isolines (isopleths) to be drawn (Figure 5.6). Isopleths are thus lines which join all places having an equal value. Common isopleths include contours (showing height), isotherms (temperatures), isobars (air pressure) or isohalines (salinity of the sea), though isopleths can be used for plotting of less usual quantities, e.g. journey times from a particular transport nodal point, cost variations across a surface or economic potential within a large land unit (Figure 5.7).

d) *Point.* The previous examples were all maps plotting distributions which are spatially extensive. However, many distributions of both physical and human factors will be punctiformal, i.e. on a map they will appear as points which may show dispersion patterns tending towards an even, random or clustered distribution. Anything which is location specific may be plotted on a point map, although care must be taken since, what might appear as a point on a small scale map, e.g. a town, would appear as being spatially extensive on a large-scale map.

Figure 5.6 The Construction of an Isopleth Map



1. The point-values are located; 2. the critical isopleth of value 70 is interpolated, with the aid of crosses placed between pairs of values at a distance proportional to the value of each; 3. other isopleths are similarly interpolated; 4. a system of density shading is applied for clarity between the isopleths.

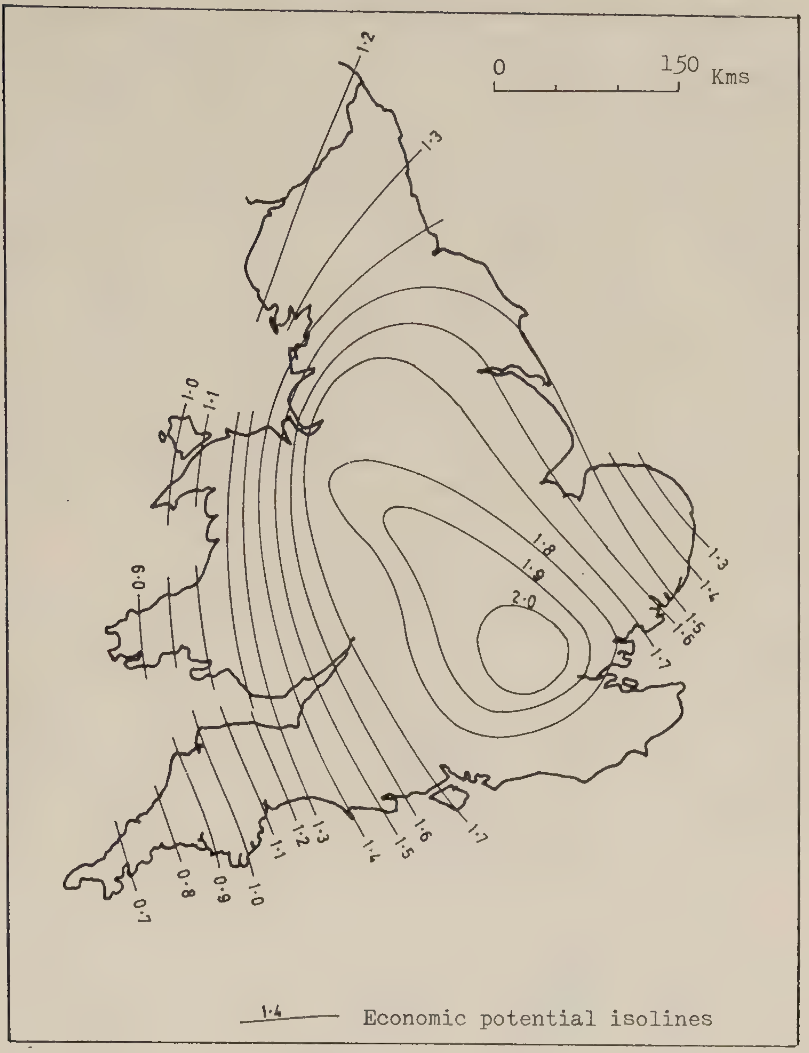
e) Linear. A third form of distribution (after spatially extensive and punctiformal) is linear. Though a number of features show linear distributions, the best known are physical features such as rivers, or human features which are usually associated with communications, e.g. roads, railways, air routes, pipelines, electricity transmission lines, etc. Linear maps can either select one theme and simply show its actual line or routeway, or they can be volumetric by showing lines of movement such that the width of the line is proportional to the volume of goods or traffic using the routes (Figure 5.8).

5.3.2 Thematic Map Considerations for Aquaculture and Inland Fisheries

In sections 2.3, 2.4 and 2.5 we listed over 30 production functions which normally show spatial variability. It would be possible to draw up thematic maps to represent any of these functions, though this would not always be necessary since, as shown in section 5.2, topographic maps can sometimes give sufficient information.

Space precludes an examination of how best thematic maps could be drawn up for each necessary function - instead here we will concentrate on some important requisite considerations and in the next section we will look at worked examples of how some more complex thematic maps might be derived.

Figure 5.7 Economic Potential Isopleths for England and Wales (from Clark, 1966)



Though there might be an optimum or obvious way to draw up a thematic map for any production function, maps could in fact be drawn up in several ways, i.e. the method used would be determined by the way in which the map could best be understood, or the way in which it was going to be used. To exemplify this, consider a map showing "water quantity". A normal thematic map showing this function would be linear in type, with differentiation of quantity being shown by colour or by differences in the width of stretches of waterway (Figure 5.9). This map would then be easily understood and, given that sufficient information was available on the water quantitative parameters, the map could form the basis of further action.

However, if a map of water quantity was required for integration into some forms of GIS, then it might be desirable to produce a choropleth map showing some measure of water quantity as a complete mapped surface (Figure 5.10). Careful consideration would need to be given as to how the water quantity measurement (or score) was going to be derived for a complete aerial unit.

Figure 5.8 Flowlines Showing Fish Transport Routes in Malawi (from Balarin, 1987)

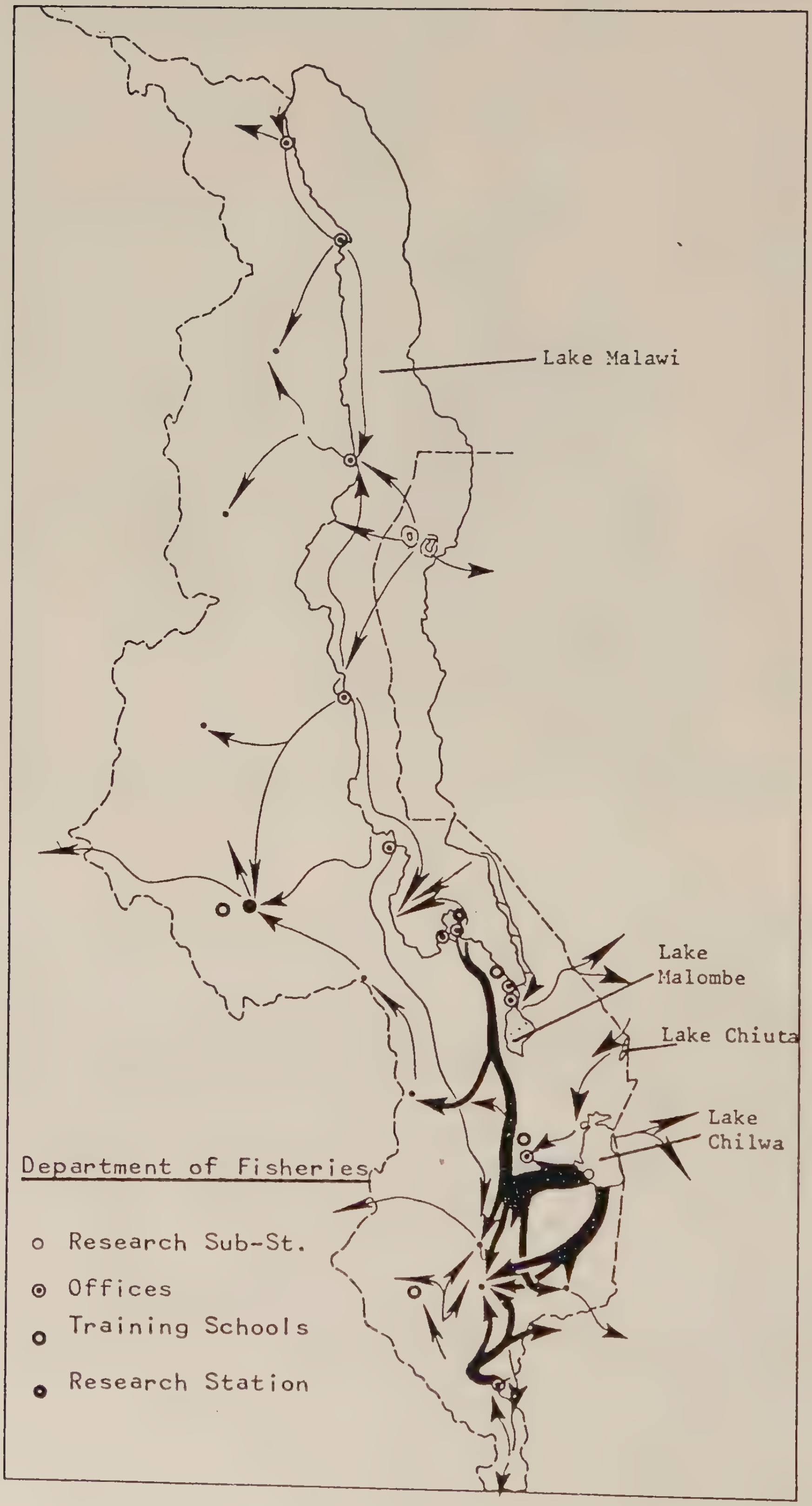
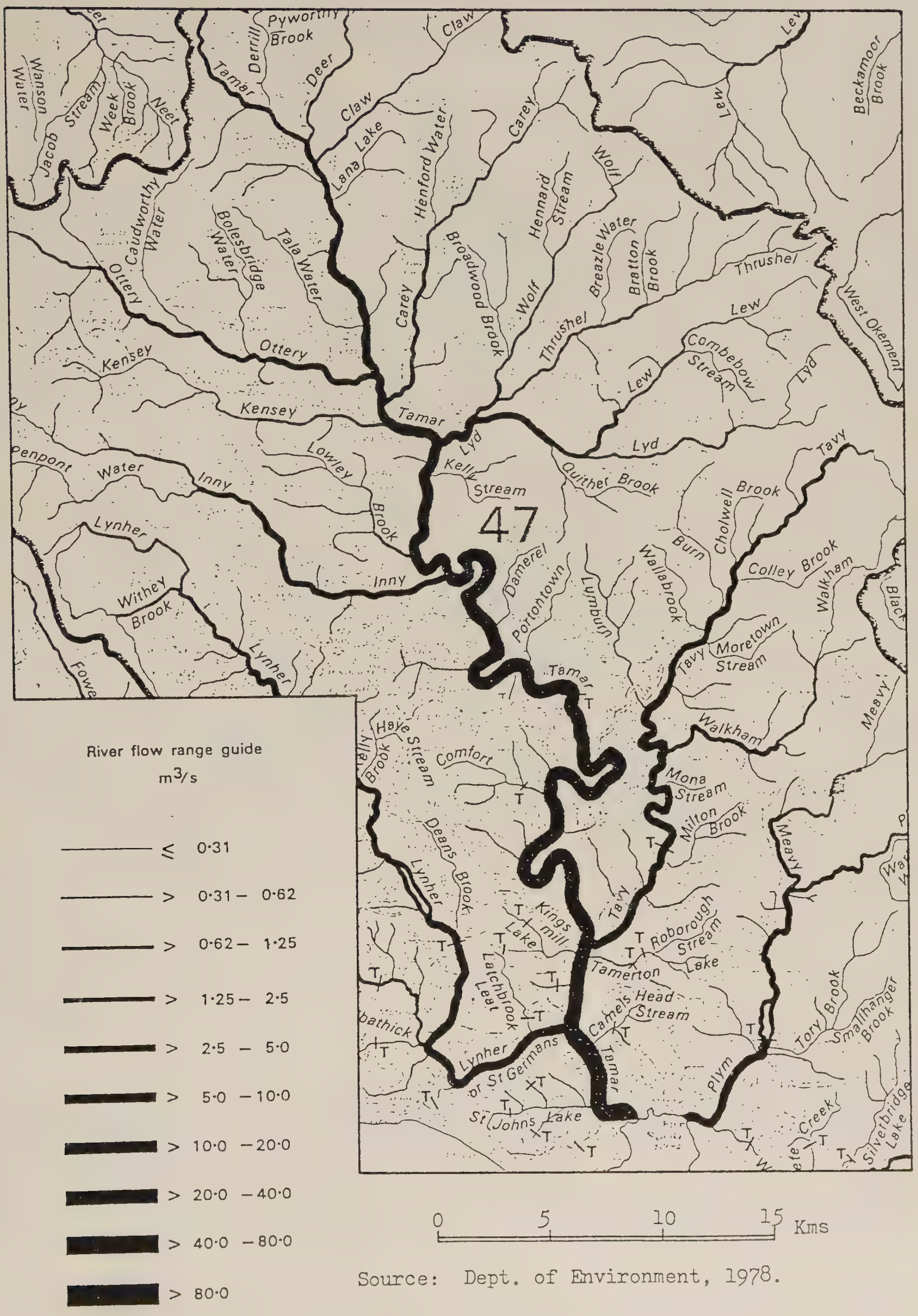
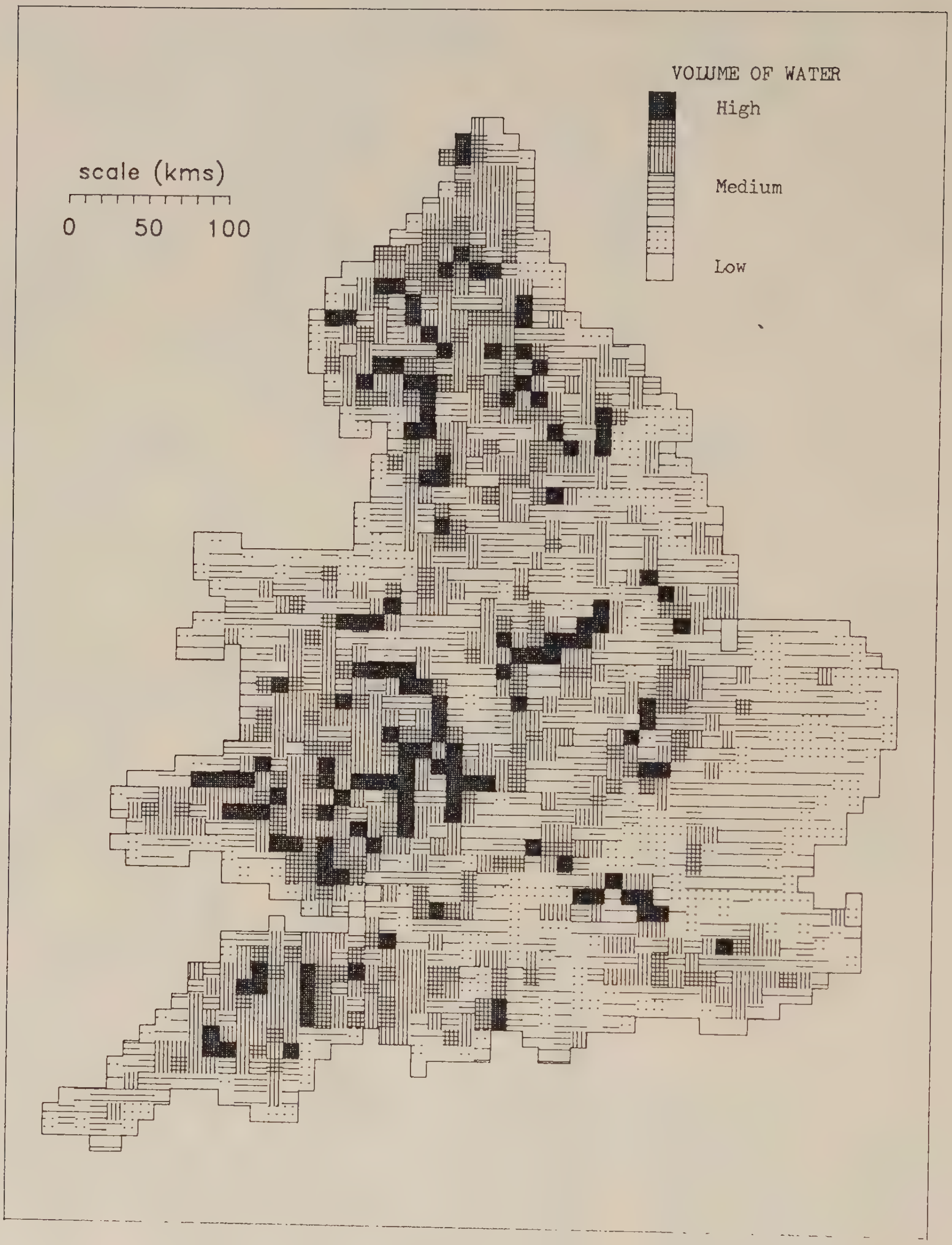

Lake Malawi
Lake Malombe
Lake Chiuta
Lake Chilwa
Department of Fisheries
o Research Sub-St.
⊙ Offices
o Training Schools
● Research Station

Figure 5.9 Linear Map Showing Water Quantity Variations


Wanson Water
Jacob Stream
Week Brook
Neet
Tamar
Derrill
Pyworthy Brook
Deer
Claw
Lana Lake
Henford Water
Carey
Wolf
Hennard Stream
Lew
Beckamoor Brook
Caudworthy Water
Bolesbridge Water
Tala Water
Ottery
Broadwood Brook
Breazle Water
Bratton Brook
Thrushel
West Okement
Kensey
Combebow Stream
Lyd
Kelly Stream
Quither Brook
Penpont Water
Inny
Lowley Brook
Lynher
Withey Brook
47
Damerel
Portontown
Lumburn
Wallabrook
Burn
Cholwell Brook
Tavy
Colley Brook
Walkham
Black
Moretown Stream
Meavy
Fowey
Haye Stream
Kelly Brook
Comfort
Mona Stream
Milton Brook
Deans Brook
Kingsmill Lake
Roborough Stream
Latchbrook Leat
Tamerton Lake
Camels Head Stream
Tory Brook
Smallhanger Brook
St Germans or Lynher
St Johns Lake
Plym
Creek
Silverbridge Lake
T
River flow range guide
m3/s
≤ 0·31
> 0·31 – 0·62
> 0·62 – 1·25
> 1·25 – 2·5
> 2·5 – 5·0
> 5·0 – 10·0
> 10·0 – 20·0
> 20·0 – 40·0
> 40·0 – 80·0
> 80·0
0
5
10
15
Kms

Source: Dept. of Environment, 1978.

Figure 5.10 Choropleth Map Showing Water Quantity Variations in England and Wales



It is also possible to create these complete mapped surfaces for functions having point distributions, e.g. such as "agglomeration", and for those which are concerned with the availability of particular inputs (which would originate from one or more mapped points - perhaps large towns). In these cases, the "score" given to any area would necessarily be calculated as being some function of the distance from another fish farm or from the source of the input, i.e. this might be a time, distance or cost function. As we will show in Chapter 6, this ability to convert all thematic maps to form complete mapped surfaces is extremely convenient for the success of GIS.

Very few of the thematic maps which would be relevant to aquaculture or inland fisheries would be available for purchase or acquisition as "off-the-shelf" products. Those that might include some soil, climatic and water quality maps, plus the topographic maps which form the basis of thematically mapping those functions discussed in section 5.2. Clearly, thematic maps are not generally available because they would rarely be in demand, although many are also not available because the subject (theme) being mapped might undergo frequent changes in its distribution, e.g. "land costs" and "current fishing levels".

The possibility and ease of drawing up thematic maps would vary greatly from function to function, depending on how much primary and secondary data was readily available, the complexity of the distribution being shown and on the detail in which the map was being drawn. Relatively easy maps to construct would include those showing "agglomeration", "climatic factors" and "areas designated for other activities". For these maps the straightforward plotting of point, choropleth and chorochromatic distributions respectively may be sufficient, and the data, in many cases, would be easy to acquire. Other production functions would be easy to map if only their data were not so difficult to acquire. These include the functions of "relationship between income levels and fish protein costs", "the social acceptability of aquaculture as a food production practice" and "the prevalence of predators". The data is difficult to acquire because large-scale and quite detailed surveys would be needed which would not be considered as cost-effective. Finally, as we indicated in section 3.4, for some functions the data for producing maps would simply be unavailable and/or unobtainable, so proxy data might have to be used.

5.4 The Derivation of Some More Complex Thematic Maps

In this section we have deliberately chosen a number of worked examples which give both a wide range of common production function types and a wide range of methods for drawing up the derived thematic maps. Although the examples are all taken from Meaden (1986), and are therefore only concerned with one type of aquaculture in one general location, the methods shown would be applicable in any situation where the necessary data could be obtained, i.e. we are concerned here with the principles, the potential and the methodologies which might be used. Our main aim is to give ideas about "spatial scoring", to point out some of the many factors which have to be considered, and to underscore the fact that in any operations performed by GISs the user may need to procure or collect a wide variety of mappable data. What thematic mapping is actually done, or is possible, is determined by the use to which it is proposed, the time available, the detail required and the cost-effectiveness of getting the data.

In each example we will indicate the necessary source data, the general methods used and any simplifying assumptions that are inevitably necessary in modelling real world situations. The actual methods of carrying out some of the procedures could be done in several ways - these might be dependent upon the hardware and software available, or other resources, though most of the repetitive calculations shown would clearly best be performed within a GIS. The importance of outlining simplifying assumptions lies both in illustrating how the methodology might limit the accuracy of the final mapped surfaces, and in pointing to the problems and dangers of attempted simplification. In the examples shown, the final thematic maps produced were all choropleth maps based on a 10km x 10km grid cell, and they were all scored on a 0 to 10 scale. The use of "scores" was made since these gave some relative indication of the ability of individual cells to provide for the particular production function, and they were useful because they surmounted the problem of integrating data having different measurement forms. However, it would clearly not be necessary to use this scoring system - the thematic maps could simply be "derived" and left unscored.

5.4.1 Water Quantity Maps

A) *Sources Used.*

i) A "River Pollution Survey" map covering England and Wales at a scale of 1:250 000 (Dept.of Environment, 1978). As well as showing river water quality by four classes, the map showed the mean water flow volumes of rivers by 10 flow categories (Figure 5.9).

ii) Computer print-out data giving river flow rates for 576 flow gauging stations in England and Wales.

iii) Maps showing the location of these gauging stations.

B) *Methods Used.*

The fish farmer must be concerned with the total volume of water available, plus the potential accessibility and the flow rate variability of that water. The pollution survey map gives sufficient detail on the first two of these. To show variability of river flow a map was constructed, part of which is shown in Figure 5.11, using data from the 576 flow gauging stations. Variability, for this exercise, equalled the ratio between the 1% exceedence flow rate and the 99% exceedence flow rate of the river. Absolute maximum and minimum flow rates were not used because these rates could be suspect due to difficulties of measuring extreme flows. Also, because the flow rate data had been collected over a considerable time period, then in many cases the monitoring equipment had been improved or the river flow rate had been moderated by various water engineering projects.

Figure 5.11 consists of isopleths which were interpolated from a plot of the 576 variability ratio figures. The map uses six classes which have geometric intervals because of the nature of the frequency distribution shown when the variability ratios were plotted (Figure 2.4). In interpolating the isopleths in Figure 5.11, a knowledge of factors which affect stream flow variability was incorporated.

To achieve a choropleth map showing a "scored" surface, three stages were followed:

i) For each 10km cell a "relative water volume and accessibility" score was calculated using the formula:

$$v = \frac{\sum_{i}^{r} (t.w) + t}{20}$$

where v = "relative water volume and accessibility" score,
t = total length (in mapped kilometers) of all fresh waterways in the cell, i.e. to tidal limit where relevant,
i....r = each of the 10 categories of river flow range,
w = weightings as per Table 5.2.

As it is impossible to state objectively the proportion of water which might be available from any particular waterway it was assumed that, with increasing waterway size, a decreasing proportion of water would actually be both practically obtainable and potentially available, i.e. equal to the square root of the volume. As well as the total volume of water in any cell, it was

Figure 5.11 Variability of River Water Flow in the North of England

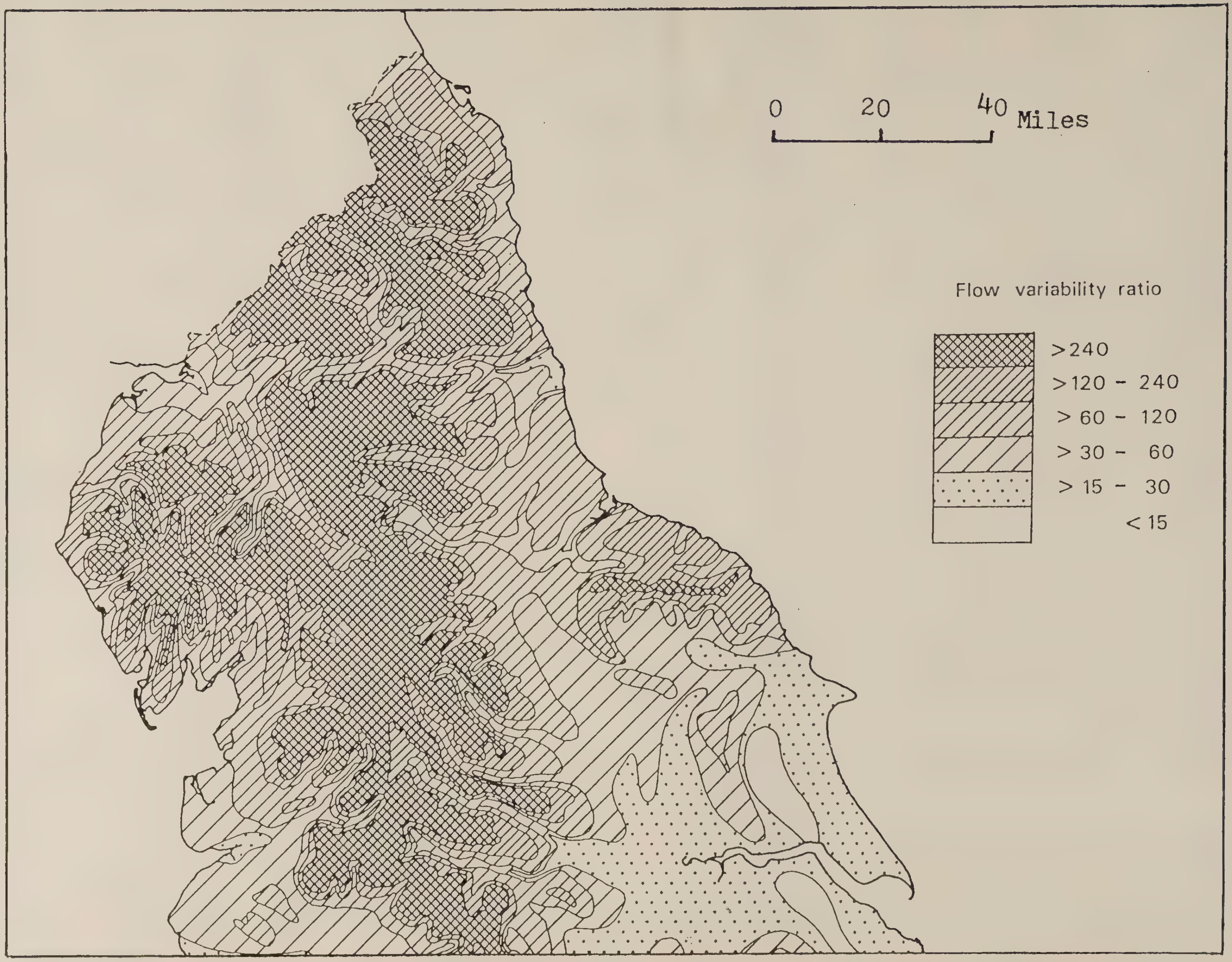

0
20
40 Miles
Flow variability ratio
>240
>120 - 240
> 60 - 120
> 30 - 60
> 15 - 30
< 15

Table 5.2 Weightings Allocated to River Flow Categories

Flow Range (cumecs)	Relative Volume of Water	Weighting (square root of vol.)
<0.31	1	1
0.31 - <0.62	2	1.4
0.62 - <1.25	4	2.0
1.25 - <2.50	8	2.8
2.50 - <5.00	16	4.0
5.00 - <10.00	32	5.7
10.00 - <20.00	64	8.0
20.00 - <40.00	128	11.3
40.00 - <80.00	256	16.0
80.00	512	22.6

essential to include an allowance for river frontage access to water. If no allowance was made then a cell having a short, high water volume stretch of river and long stretches of small volume streams, might seem to offer more potential for fish farming than a cell where the situation was reversed - this would not be the case.

ii) Using the "variability of water flow" map (Figure 5.11) a "variability score" was calculated for each cell using the formula:

$$s = \frac{\sum_{i}^{n} (x \, . \, y)}{100}$$

where s = "variability score",
x = percentage of surface area of the cell in each variability class,
y = weighting as per Table 5.3,
i....n = each class of variability ratio.

Table 5.3 Weighting Allocations to Variability Ratio Classes

Class	Variability Ratio	Weighting
1	<15	10
2	>15 - 30	8
3	>30 - 60	6
4	>60 - 120	4
5	>120 - 240	2
6	>240	1

iii) A final "score" for each cell was achieved by multiplying the "v" score by the "s" score and then converting the answer to a number between 0 and 10, i.e. by using a probability distribution graph which plotted all possible products (answers) achieved when multiplying together all combinations of integers between zero and 10. Cells receiving a high score would be those having a large volume of water, extensively accessible, and where there was little variation in the river flow range.

C) *Simplifying Assumptions.*

i) It was assumed that the "relative water volume and accessibility" factor and the "variability ratio" factor were of equal significance.

ii) It was assumed that the quantity of water potentially available was equal to the square root of the mean water flow rate.

iii) It was difficult to determine the exact length of waterways from the pollution survey map, because the thickness of the flow line tended to obscure smaller mapped bends in the river.

iv) A reservoir might have been built on a waterway since collection of the flow rate data commenced. This would cause the variability ratios to be greatly decreased for all downstream locations. Allowance could be made for this by obtaining data on recent reservoir construction dates.

v) Some waterways shown on the base map might be intermittent streams and thus be totally unsuited to fish farming.

5.4.2 Water Temperature Maps

A) *Sources Used.*

i) Computer print-out data giving weekly or fortnightly river water temperature information from 194 harmonized monitoring stations in England and Wales.

ii) "Average Annual Rainfall" maps - Sheet Nos. Met. 0.886 (SB) and Met. 0.886 (NB), published by the Meteorological Office (1977), at a scale of 1:625 000.

iii) "Hydrogeological Map of England and Wales, published by the Institute of Geological Sciences (1977), at a scale of 1:625 000.

iv) Ordnance Survey - Fifth Series sheets covering England and Wales, at a scale of 1:250 000 (e.g. Figure 5.1 (c)).

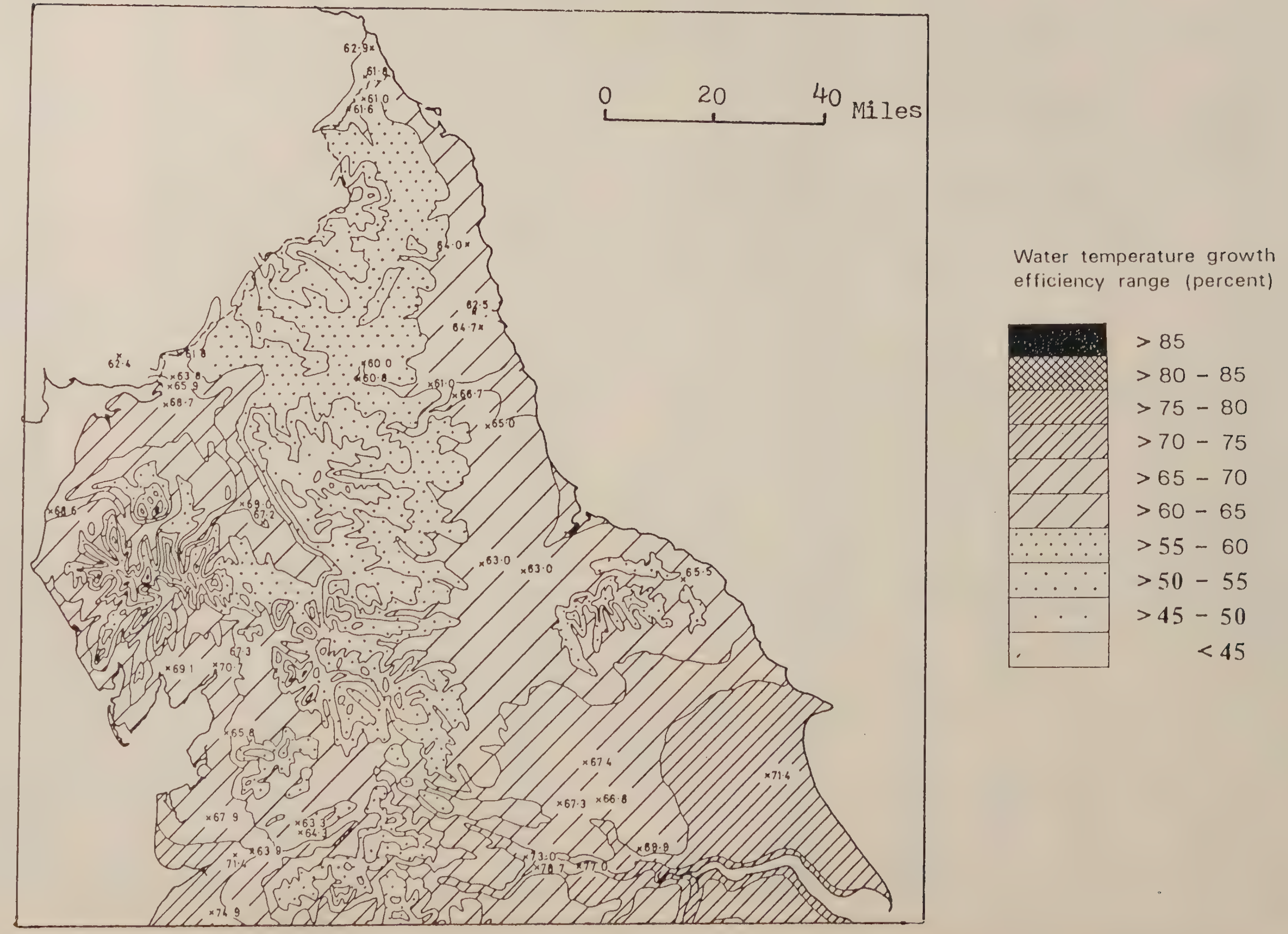
v) "River Pollution Survey" maps (Dept. of Environment, 1978) covering England and Wales at a scale of 1:250 000.

vi) The sources listed under Figure 5.13 for obtaining salmonid growth rates at different water temperatures.

B) *Methods Used.*

Using the above sources a map was constructed, part of which is shown in Figure 5.12, at a scale of 1:625 000, which showed the ability of river water temperatures to meet an optimum water temperature for trout growth of 15C. The stages in its construction were as follows:

Figure 5.12 The Efficiency of River Water Temperatures in Northern England to Provide for Trout Growth


0
20
40
Miles
Water temperature growth efficiency range (percent)
> 85
> 80 - 85
> 75 - 80
> 70 - 75
> 65 - 70
> 60 - 65
> 55 - 60
> 50 - 55
> 45 - 50
< 45
62·9
61·8
61·0
61·6
64·0
62·5
64·7
60·0
60·8
61·0
66·7
65·0
62·4
61·8
63·8
65·9
68·7
68·6
69·0
67·2
63·0
63·0
65·5
67·3
69·1
70·
65·8
67·4
71·4
67·3
66·8
67·9
63·3
64·3
63·9
71·4
68·9
73·0
78·7
77·0
74·9

i) A "best-fit" curve was plotted from a series of curves and points showing salmonid growth rates against water temperatures (Figure 5.13). A best-fit curve was used since the data exhibited slight variations, especially in the amount of one-way linear stretch parallel to the growth axis, i.e. because experimental conditions varied as did species and ages of salmonids being studied. The curve purported to show, for all possible water temperatures, standardized specific growth rates for salmonids (% weight gain per day) and the percentage of maximum growth rate attainable, i.e. the "water temperature growth efficiency" given that the optimum growth rate, occurring at 15°C, represented 100% efficiency. Thus, if the water temperature was at 10°C then trout would only be growing at 78.4% of maximum efficiency, because at 10°C the specific weight gain per day is 1.17% v. 1.5% per day at 15°C. The apex of the curve was deliberately biased towards higher temperatures because it has been shown (Aitken, 1971) that with high fat diets being extensively used, optimum water temperatures could be slightly increased, as could growth rates at any water temperature. Additionally, since the optimum water temperature for growth decreases as the ration decreases (Shelbourn *et al,* 1973; Elliott, 1975), then it would be realistic to look at a higher figure (for optimum growth) about which to fit a curve, i.e. if the trout are being fed to satiation as is frequent aquacultural practise.

ii) For each temperature recorded on the computer listings for each of the 194 monitoring stations, percentage "water temperature growth efficiency" figures were substituted, as derived from Figure 5.13. From these figures a single mean percentage "water temperature growth efficiency" score was calculated for each station, using the formula:

$$\bar{x} = \frac{x}{n}$$

where x = "water temperature growth efficiency" figure (%),
n = number of water temperature readings on the harmonized monitoring station listing

iii) The mean percentage "water temperature growth efficiency" figures were plotted on a base map of England and Wales (Figure 5.12).

iv) Isolines were then plotted on the base map at 5% "water temperature growth efficiency" intervals. In interpolating these isolines due consideration was made for altitude, latitude, run-off, geology and thermal effluents as these factors may have macro-scale influences on prevailing water temperatures. Extra interpolation points were generated in highland areas with the necessary altitudinal water lapse rate data being obtained from known air lapse rates. These temperature reductions were made from the actual mean water temperatures as recorded at monitoring stations having a nearby location, a similar latitude and run-off rate and a known altitude.

v) For the purposes of the original study, the information shown on the "water temperature efficiency" map was converted to scores, on the 0 to 10 scale, for each 10km cell covering England and Wales, but we need not elaborate here on the method used. Many of the lengthy calculations and the map interpolations could quickly be done using a GIS.

C) *Simplifying Assumptions.*

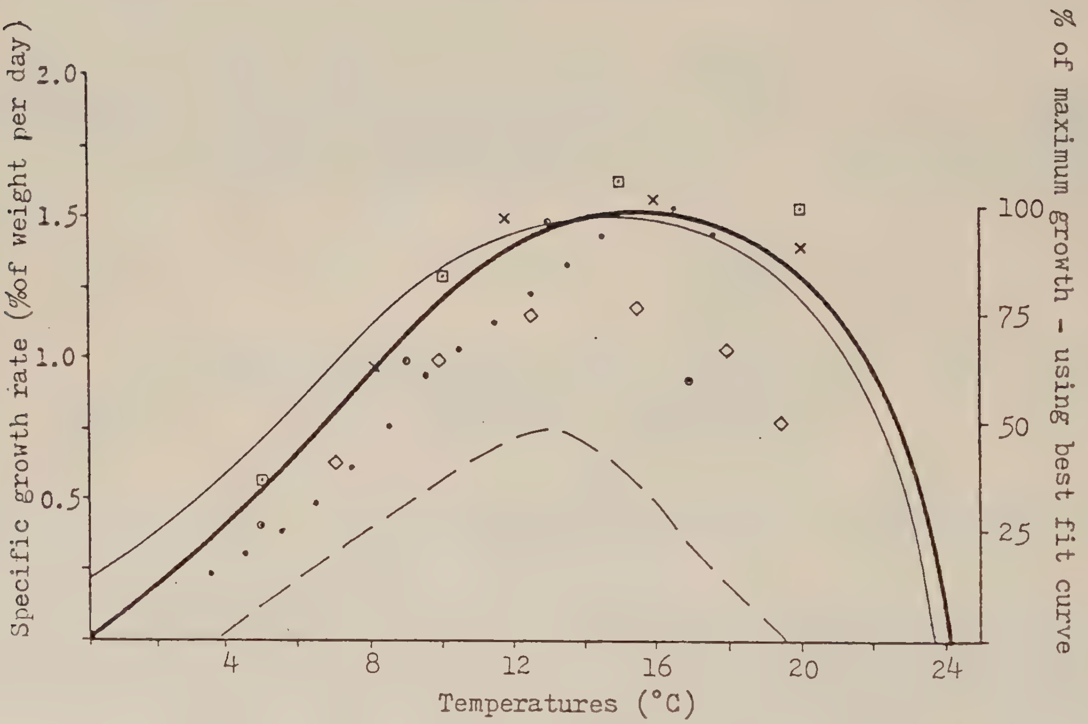
i) It could be argued that the use of annual mean "water temperature growth efficiency" figures upon which to base the isoline map was meaningless since this could disguise large deviations about the mean. However, this was seldom the case - in fact nearly all other climatic data show far greater measurement deviations than water temperatures.

ii) It was assumed that various salmonid species grow at the same rate and exhibit the same growth against water temperature curve. There is some evidence to show that this is approximately correct (Nicholls, 1957).

iii) It was assumed that water temperature lapse rates are equivalent to air temperature lapse rates, are uniform and can be readily assessed from nearby waterways having a similar milieu. This is generally true.

iv) It was assumed that the use of a single weekly or fortnightly water temperature reading, over a five-year period, could form the basis of a reliable "water temperature growth efficiency" score.

Figure 5.13 Best-Fit Curvilinear Regression Line Fitted to Curves or Points Showing Salmonid Growth Rates Against Water Temperatures



Sources and Species

——— Brett, et al (1969) - Sockeye Salmon (Oncorhynchus nerka); (7 - 12 month old).

◇ ◇ ◇ McCormick, et al (1972) - Brook Trout (Salvelinus fontinalis)+.

▣ ▣ ▣ ▣ Shelbourn, et al (1973) - Sockeye Salmon (Oncorhynchus nerka)+.

· · · . Brett (1974) - Sockeye Salmon (Oncorhynchus nerka); (30 gramme fish).

— — — Elliott (1975) - Brown Trout (Salmo trutta); (17 gramme fish).

• • • • Hokanson, et al (1977) - Rainbow Trout (Salmo gairdneri).

× × × Brown (personal communication, 18/7/80) - Rainbow Trout (Salmo gairdneri); (15 cm fish - high fat diet).

▬▬ 'Best Fit' curve.

+ The vertical axes were reduced by a factor of four because these experiments were conducted on fry who have very rapid specific growth rates. The final results are not affected since it is the shape along the horizontal axis which is important.

5.4.3 Maps Showing the Availability of Underground Water

A) *Sources Used*

i) "Hydrogeological Map of England and Wales" (1977) at a scale of 1:625 000. This map indicates aquifer flow potential and main characteristics, in 49 sub-categories of geological formation.

ii) "Water Industry - Map 2 - Major Sources of Water Supply", published by the National Water Council (1980), at a scale of 1:625 000.

iii) Data, obtained by standardized questions put to each Water Authority chief hydrologist, relating to the likelihood of being able to procure access to existing underground water supplies.

B) *Methods Used.*

Considerations concerning the availability of underground water can be divided into two main types for mapping purposes. The first, for which the hydrological maps could be used in their existing form, was simply the existence of, and available quantities of, aquifer water. The other consideration relates to the likelihood of being able to obtain an abstraction licence to exploit the aquifer.

From the questions put to the chief hydrologists, a map was produced (Figure 5.14) showing the likelihood of being able to procure a licence to abstract underground sources of water. It was only possible to classify the area into three broad divisions, and it is pertinent to note that there are no areas in England and Wales where an abstraction licence could "certainly" be obtained.

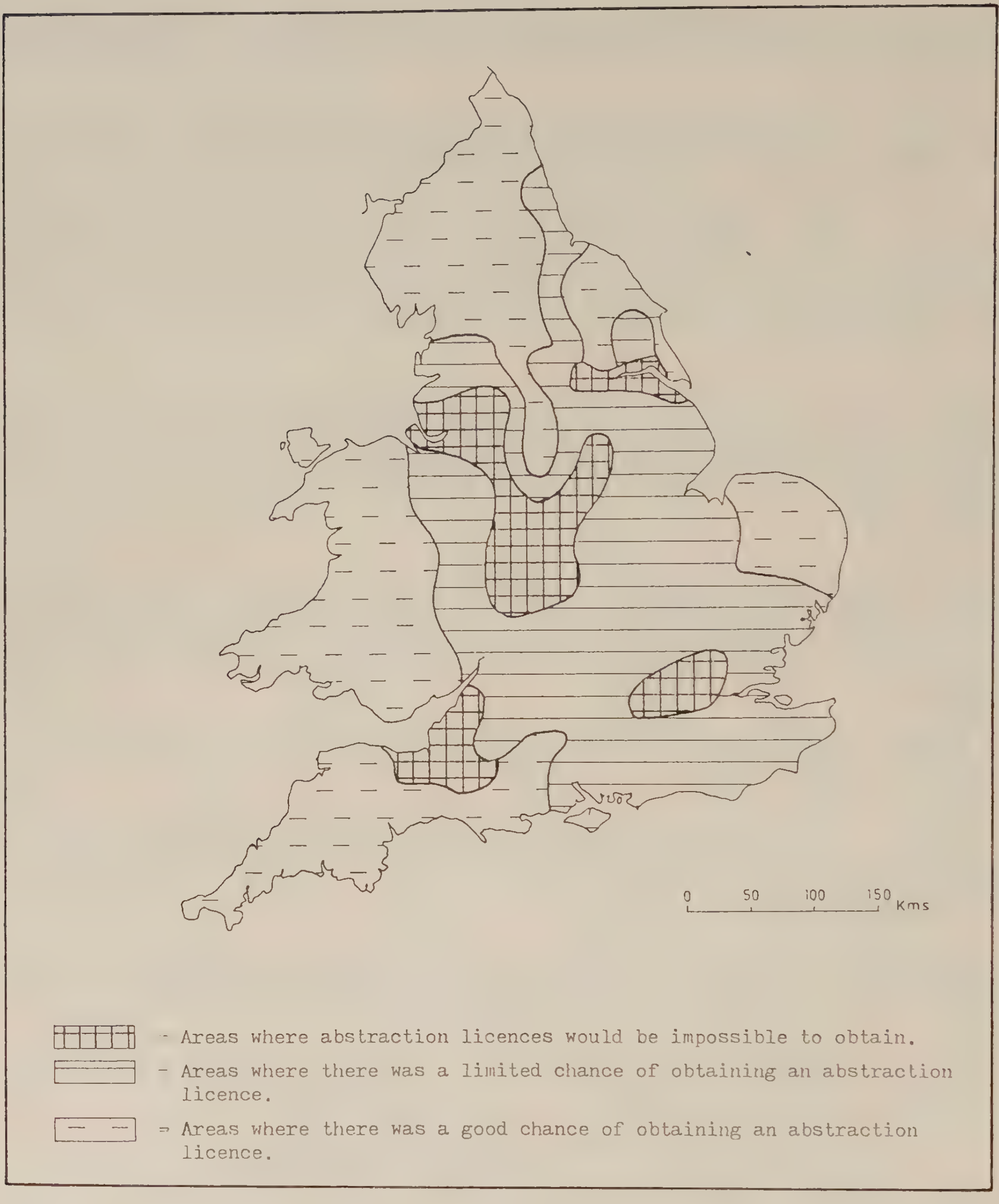
To produce a final choropleth map showing the availability of underground water, the following steps were followed:

i) Each of the 49 sub-categories of geological formation shown on the hydrogeological map was allocated a "supply score" based on the ability of the sub-category to supply underground water (Table 5.4).

Table 5.4 Water "Supply Score" Allocated by Yield of Aquifer

Yield of aquifer (litres per second)	"Supply Score"
<10	0
>10 - 20	1
>20 - 30	2
>30 - 40	3
>40 - 50	4
>50 - 60	5
>60 - 70	6
>70 - 80	7
>80 - 90	8
>90 - 100	9
>100	10

Figure 5.14 The Likelihood of Being Able to Procure a Licence to Abstract underground Sources of Water in England and Wales


0 50 100 150 Kms
▦ - Areas where abstraction licences would be impossible to obtain.
▤ - Areas where there was a limited chance of obtaining an abstraction licence.
- Areas where there was a good chance of obtaining an abstraction licence.

ii) A transparent overlay, having a 10km square grid at the 1:625 000 scale, was placed over the hydrogeological map and the percentage in each of the aquifer yield classes in each 10km cell was calculated, and the figure obtained for each was multiplied by the "supply score". This resulted in an aggregate total for each cell in the range of zero to 1 000.

iii) The transparent overlay was then placed over the map showing the likelihood of being able to procure underground water. The aggregate score for each cell obtained in (ii) above was then adjusted to allow for spatial variations in this likelihood of obtaining underground water. Adjustments were as follows:

a) Scores for cells in regions where an abstraction licence would be impossible to obtain were reduced to zero.
b) Scores for cells where there was a chance of obtaining an abstraction licence were divided by two.
c) Scores for cells in areas where there was a good chance of obtaining an abstraction licence remained unaltered.

Suitable adjustments were made for cells which may have been partly in two or more regions.

iv) The adjusted aggregate figures were then divided by 100 and rounded off to the nearest whole number to achieve a final score for each cell in the range of 0 to 10. A high score represented a cell in which aquifers could supply high yields of water and where there was a good chance of obtaining an abstraction licence.

C) *Simplifying Assumptions.*

i) The adjustments made in (iii) above were thought to give a reasonable "penalty" to the various areas.

ii) Cognizance could only be taken of the near surface mapped hydrogeological classifications of base rock, i.e. there may be deeper-lying water-bearing sub-strata.

iii) Each of the 10 Water Authority chief hydrologists might have had a different perception of what was meant by, for instance, "a limited chance of" or "a good chance of" obtaining an abstraction licence, i.e. it is very difficult to standardize perceptual questions.

iv) It was only possible to draw estimated boundaries between the three types of abstraction region.

v) The granting of an abstraction licence may actually depend upon the location of existing boreholes. Allowances could not be made for this since policies vary between and within Authorities and because suitable data on the distribution of boreholes was often non-existent.

vi) The fact of being located near to an existing surface waterway, for the disposal of used water, was not allowed for. This is not a problem over most of England but it might be in some areas.

5.4.4 Relief Maps

A) *Sources Used*

i) Ordnance Survey - Fifth Series sheets covering England and Wales at a scale of 1:250 000 (e.g. Figure 5.1 (c)).

B) *Methods Used.*

i) A transparent overlay having a 10km square grid at the 1:250 000 scale, with each 10km cell being further divided into 100 x 4mm square cells (1 km^2), was placed in turn over each of the Ordnance Survey sheets.

ii) A count was made of the number of 4mm cells within each mapped 10km cell which contained either of the following:

a) Where three consecutive contours were not more than 2mm apart. This would indicate areas having at least a 400 feet slope with a gradient of 1 in 4 over some of the 4mm cell.

b) Where there was evidence of marsh-land, artificial drainage, excessive meandering or "interconnections" (braiding) along river flood plains, i.e. where poor drainage or flooding was likely.

iii) A score for each cell, in the range of 0 to 10, was achieved using the formula:

$$0 = \frac{100 - \Sigma(n+m)}{10}$$

where o = the obtained score,
n = the number of 4mm cells which contained three consecutive contours which were not more than 2mm apart,
m = the number of 4mm cells where poor drainage or flooding was likely.

Answers were rounded to the nearest whole number. Cells receiving high scores would be ones that exhibited no map evidence of large-scale steep slopes or of being situated where flat land on river flood plains was an impediment to drainage and/or liable to flooding. For those kinds of aquaculture where a constant high throughflow of water was not essential, then flat land on flood plains might in fact be advantageous, so any scoring system would need to reflect this.

C) *Simplifying Assumptions*

i) Some portions of some of the excluded 4mm cells would undoubtedly be suitable for fish farming.

ii) The scoring method would not account for "rugged" land which had less than a 400 feet elevational range, i.e. the method was designed to eliminate larger scale rugged areas.

iii) Waterways and contour lines may not be very accurately drawn at the 1:250 000 scale. Indeed the Ordnance Survey is unable to state the criteria upon which waterways are included on 1:250 000 sheets and they admit to a degree of "cartographic licence".

iv) Some flooding could obviously occur in uncounted cells but this would be comparatively rare and impossible to allow for.

5.4.5 Land Cost Maps

A) *Sources Used.*

i) "Persons per Square Mile by Ward and Parish - 1971" map, published by Dept. of Environment (1975), at a scale of 1:1 250 000.

ii) "Land Use Capability" map, published by the Soil Survey of England and Wales (1979), at a scale of 1:1 000 000.

iii) "Economic Potential for Great Britain" map, published in Clark (1966).

iv) "Economic Potential for the Enlarged European Community" map, published in Clark *et al* (1969).

B) *Methods Used.*

It was shown in section 2.4.5 that land costs are difficult to define in map form because of constant temporal and spatial pricing adjustments. It was also suggested that land costs could best be perceived as being a function of:

a) The supply of, and demand for, land.
b) A perceived regional economic potential.
c) The quality of land.

Although any one of the three functions individually would not provide a very accurate mapped surface showing likely land costs, by integrating the source maps a reasonable "land cost surface" map could be generated which would give sufficient accuracy to compare the relative costs of land throughout the area. Both the "population density" map and the "land use capability" map could be utilized as they were, but the two "economic potential" maps were combined (by aggregating their economic potential isoline values) to form a "revised economic potential map of England and Wales" (Figure 5.7).

Integration of the three maps to produce a final choropleth map showing land costs was carried out as follows:

i) Over the population density map a 10km square transparency grid was placed. A "relative population density score" for each cell was established using the formula:

$$r = \sum_{g}^{l} (n \cdot w)$$

where r = "relative population density score",
n = number of square mile units within each cell,
w = weighting as per Table 5.5,
g....l = each of the six population density classes on the population map.

Table 5.5 Weightings Allocated to Classes of Population Density

Population Density Class (per square mile)	Weighting
<25	0.025
>25 - 50	0.05
>50 - 400	0.075
>400 - 6400	0.10
>6400 - 25000	0.125
>25000	0.15

The weightings in Table 5.5 were designed to give a realistic balance between the likely prices of land in different sized population centers, and such that the range of scores achieved for each cell would be from 0.1 to 6.0.

ii) Over the revised economic potential map (Figure 5.7) a 10km transparent grid was placed, and a score for each cell was established, it being the nearest index of economic potential isoline number (to one decimal place) prevailing at the center of the cell. The range of scores achieved would be from 0.7 to 2.0.

iii) To introduce the land use capability factor each of the land use capability classes shown on the map were given a weighting (Table 5.6). Over the map a 10km transparent grid was placed and the percentage of each class of land, for each cell was established. A "land use capability score" was calculated using the formula:

$$u = \frac{\sum_{c}^{j} (p \cdot w)}{100}$$

where u = "land use capability score",
p = percentage of each class of land,
w = weighting allocated to each class as per Table 5.6,
c....j = each class of land use capability.

Table 5.6 Weightings Allocated to Classes of Land Use Capability

Land Use Capability Class	Weighting
Urban land	4.0
Class 1	3.0
" 2	2.5
" 3	2.0
" 4	1.5
" 5	1.0
" 6	0.5
" 7	0

The range of scores achieved would be 0.3 to 4.0.

iv) An aggregate total for each cell was achieved by summing the three scores for "relative population density", "economic potential" and "land use capability". The theoretical range of aggregate totals was 1.1 to 12.0.

v) A final score was achieved by subtracting the above aggregate total from 11 and rounding to the nearest whole number. Thus a cell which was seen to have high land values, would be disadvantageous with regard to land costs and it might receive a final score of zero. In many countries the concept of economic land costs might not always apply. In these cases some sort of mapping which incorporated "rights" to land might need to be considered.

C) *Simplifying Assumptions.*

i) It was assumed that land costs were a reflection of population density, land use capability and economic potential in the ratio of 3:2:1 respectively, and these ratios were reflected in the maximum contribution which each could make to the final score.

ii) The method of scoring would be unrealistic at the micro-scale, e.g. core areas in city centers would have low populations but high land costs. So for a micro-scale study the methodology would need to be adjusted.

iii) Though the economic potential and population density maps were rather dated, they would still give a significantly accurate basis for scoring since these variables change very slowly at the macro-scale.

5.4.6 Maps Showing Access to Road Transport

A) *Sources Used.*

i) The "Routemaster" series of Ordnance Survey sheets, published in 1979, at a scale of 1:250 000.

B) *Methods Used.*

i) Each of the four classes of roads indicated on the "Routemaster" sheets was given a weighting as per Table 5.7.

Table 5.7 Weightings Given to Different Classes of Road

Road Class	Weighting
Motorways	3
"A"	3
"B"	2
Minor	1

ii) For each 10km grid square a score was achieved using the formula:

$$s = \frac{\sum_{g}^{j} (l \, . \, w)}{24}$$

where s = score achieved,
l = length of roads in mapped kilometers,
w = weighting as per Table 5.7,
g...j = each Road Class category.

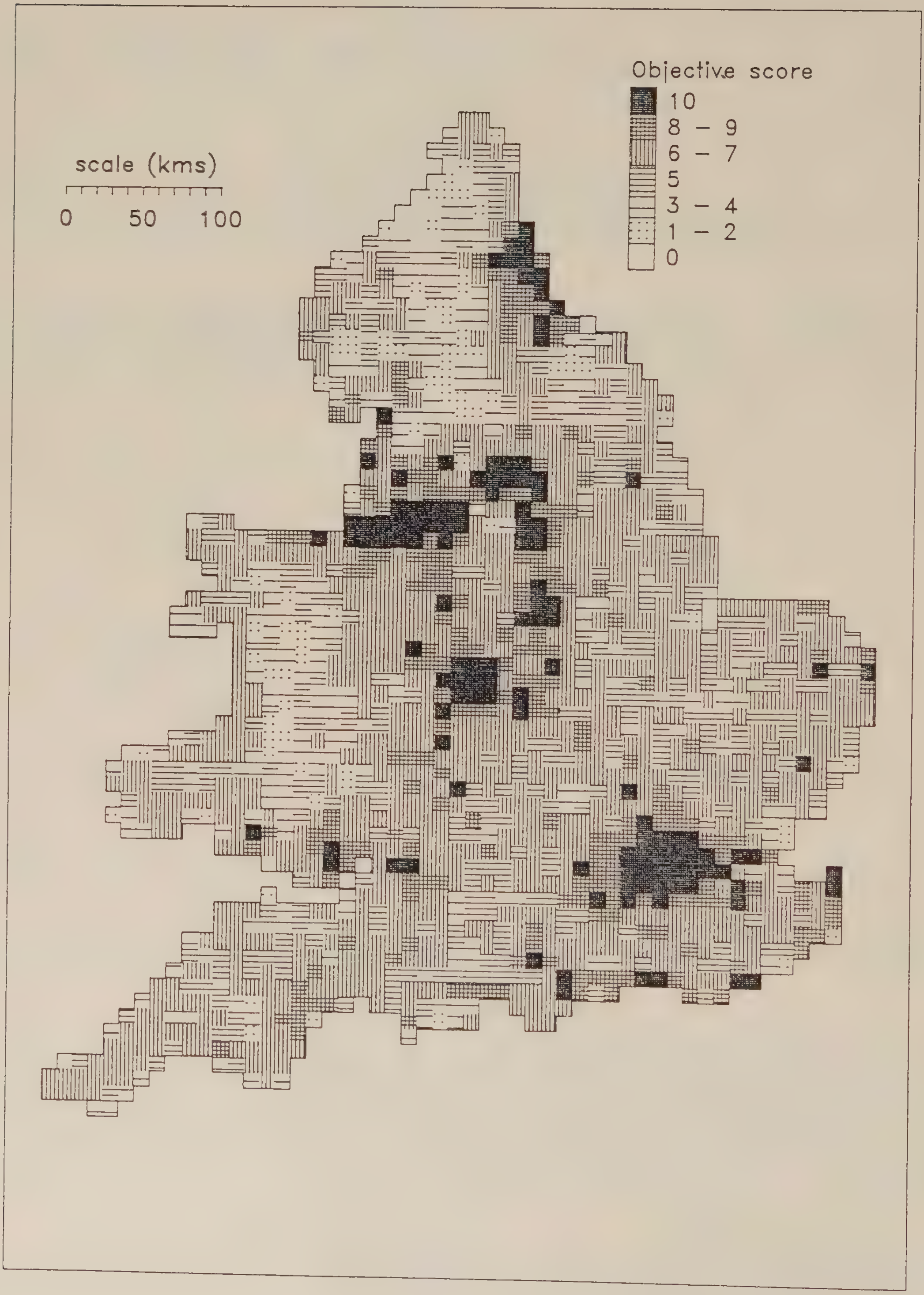
Scores for coastal cells were then calculated using the formula:

$$c = \frac{(s \times 100)}{p}$$

where additionally c = score for coastal cell,
p = percentage of the cell occupied by land.

iii) Scores were rounded to the nearest whole number and all cells scoring >9.5 were rounded to 10. Cells receiving a high score were those having a dense network of roads, especially in the Class "A" or motorway category. Figure 5.15 is given as an example of the final map showing "Access to Road Transport".

Figure 5.15 Example of the map Scored for "Access to Road Transport"


Objective score
10
8 – 9
6 – 7
5
3 – 4
1 – 2
0
scale (kms)
0
50
100

C) *Simplifying Assumptions.*

i) Though the weightings given in Table 5.7 do not reflect the volumes of traffic carried by each class of road, road transport accessibility is concerned with a variety of factors, most of which are unrelated to the traffic volume.

ii) Most tracks and farm access roads are excluded from the base maps so the realistic degree of accessibility to potential fish farm sites could not be ascertained. However, as these omissions would be relatively uniform, this problem would have little effect on the results.

iii) The coverage of urban area roads on the base map does not equate with the cover given to rural areas, though this should not detract significantly from the results.

iv) There would not be spatial uniformity in the volume of traffic using a certain class of road in different parts of the country.

v) It could be argued that considerations should be given to transport accessibility factors such as major road intersections and motorway turn-offs. However, these apparent advantages were not allowed for because of the counter-balancing factors of increased land costs and potential disturbances.

5.4.7 Maps Showing Distance From Catering Markets

A) *Sources Used.*

i) "British Hotels, Restaurants and Catering Association - Guide Book - 1980", published by the B.H.R. and C.A. (London).

ii) "A.A. - Hotels and Restaurants in Britain (1980)", published by the Automobile Association (Basingstoke).

iii) "R.A.C. - Guide and Handbook - 1980", published by the Royal Automobile Club (London).

B) *Methods Used.*

i) Since no maps existed showing the location of catering outlets in England and Wales, it was necessary to ascertain their distribution. After corresponding with all known publishers of the relevant guide, it was apparent that the above sources gave a spatially random and comprehensive coverage of catering outlets in England and Wales.

ii) Using the data sources a count was made of the number of separate hotels, guest houses and restaurants listed under each named place in England and Wales (plus the Scottish border area).This figure then represented an assumed number of catering outlets for each settlement.

iii) On a tracing overlay a map was constructed, at a scale of 1:625 000, showing the distribution of these catering outlets by the use of proportional circles. The radius of each circle was calculated using the formula:

$$r = \frac{\sqrt{p}}{4}$$

where r = radius of the circle (cms),
p = number of catering outlets shown for each settlement.

In the center of each proportional circle the actual number of catering outlets was recorded.

iv) On a transparent overlay three concentric rings were drawn, each consecutively corresponding to 12km, 24km and 36km radii at a 1:625 000 scale. It was thus initially assumed that a trout farmer would be prepared to travel a straight line distance of up to 36kms to serve catering markets.

v) Placing the central point of the concentric rings over the mid-point of each cell in turn, the number of catering outlets within each of the three market zones was counted. Because the catering markets were represented by proportional circles, thus having spatially varying extensions on the map, a market was counted as being sited in the innermost annulation that its proportional circle appeared in. This method of counting also applied to catering markets whose centers might be beyond the 36km outer circle but whose proportional circle came within the annulations. By utilizing this technique some "gravitational" allowance could be incorporated into the scoring, i.e. it would be worth travelling a little further to serve a larger market, though the extent of this frictional effect of distance is necessarily arbitrary. Figure 5.16 illustrates this methodology.

vi) A weighting was then applied in order to make allowance for the fact that catering markets in the inner zone could be more advantageously served than markets in the outer annulations. Using the formulae:

$$x_i = \sqrt{\frac{r_i^2}{2}} \qquad \text{for the inner zone}$$

$$x_{ij} = \sqrt{\frac{(r_j - r_i)^2 + 1}{2}} \qquad \text{for the second zone}$$

$$x_{i.k} = \sqrt{\frac{(r_{kj} - r_j)^2 + 2r_i}{2}} \qquad \text{for the outer zone}$$

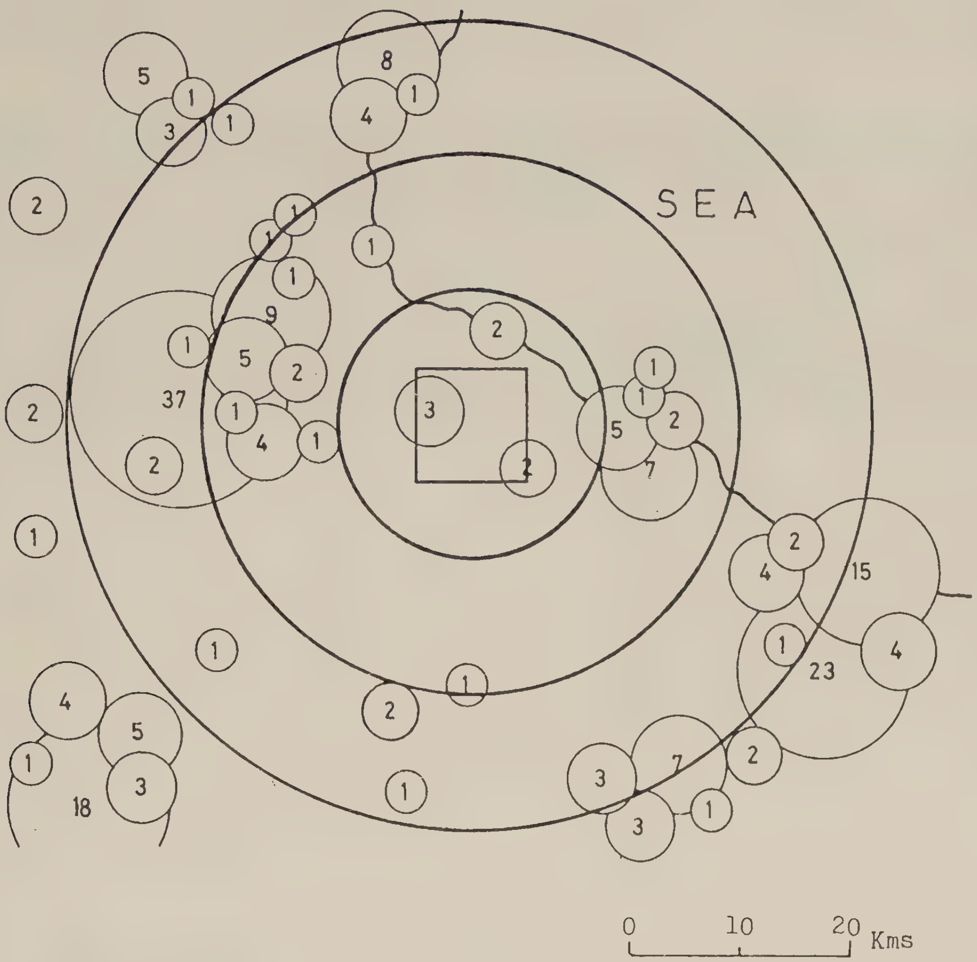
where x = the average distance needed to travel to serve all randomly distributed catering markets in each zone,
r = radius of each zone,
i...k = each successive outward zone,

the average straight line distances needed to travel to serve each of the three catering market zones, from the central point of each cell, was calculated. The results were 8.49kms, 20.49kms and 32.49kms respectively. These straight line distances were reduced to the ratios of 1, 2.41 and 3.83 respectively. Thus, on average, a trout farmer might need to travel 3.83 times as far to supply catering markets in the outer zone than in the inner zone.

In order to simplify further calculations, and to more approach reality, these ratios were rounded down so as to read 1, 2 and 3 respectively, i.e. transport costs are not linear as a function of distance - they generally decrease proportionally with distance. Using these ratios, catering outlets in the inner circle were given a weighting of 3, outlets in the middle zone 2 and outlets in the outer zone were left unweighted as 1.

vii) The number of catering outlets counted in each of the three market zones was multiplied by the three respective weightings and then the three figures were totalled.

Figure 5.16 Methodology Used to Establish Scores for Distance from Catering markets


5
1
3
1
8
1
4
SEA
2
1
1
1
1
9
1
5
2
37
2
1
4
1
2
3
2
2
1
1
5
2
7
1
2
4
15
1
23
4
1
2
1
4
5
1
3
18
2
1
3
7
3
1
2
0
10
20
Kms

Key

2 Number of catering outlets in a specific settlement.

○ Proportional circle indicating size of catering market.

| 12km, 24km and 36km radii at the 1:625,000 scale.

Scoring for the cell indicated would be:

			Weighting		Total
Catering outlets in inner zone =	12	x	3	=	36
Catering outlets in middle zone =	75	x	2	=	150
Catering outlets in outer zone =	82	x	1	=	82
			Total for cell	=	268

Note that the coastal cell having 15 catering outlets is centred some 2kms beyond the outer (36kms) concentric circle but it still counted for 'objective scoring', i.e. suggesting that a trout farmer would be prepared to travel 38 straight line kilometres to serve that settlement.

viii) A final score was then allocated to each cell using Table 5.8. A cell receiving a high score was one where many hotels and restaurants were in close proximity to, or within the "gravity field" of, the center of that cell.

A similar methodology to this could be used for supplying fish to any market sector. Calculations would be easier for supplying wholesale markets, i.e. since there are fewer of them.

Table 5.8 Scores Allocated to the Aggregate Weighted Total of Catering Outlets

Aggregate Weighted Total of Catering Outlets	Allocated Score
<150	0
>150 - 300	1
>300 - 450	2
>450 - 600	3
>600 - 750	4
>750 - 900	5
>900 - 1050	6
>1050 - 1200	7
>1200 - 1350	8
>1350 - 1500	9
>1500	10

C) Simplifying Assumptions.

i) It was assumed that each catering outlet was selling the same volume of trout. Although this is unrealistic it would have little effect on the score since there is no evidence of trout being unacceptable by region.

ii) It was impossible to verify that there was no regional bias in the choice of catering outlets listed in the data sources used.

iii) Some restaurants would be serving a foreign cuisine and thus be unlikely to sell trout, and some restaurants or hotels might be part of a large chain who practice centralized buying.

iv) Many suburban areas might be under-represented in the restaurant guides, though in practice these are likely to be areas where trout sales would be minimal.

v) Catering outlets were all considered to be centrally sited in each specific settlement. In practice this is unrealistic although the true dispersion of these outlets would rarely affect the score allocated.

CHAPTER 6 - THE FUNCTIONING AND USES OF GEOGRAPHIC INFORMATION SYSTEMS

6.1 Introduction

Referring back to Figure 1.3 (p.6) it can be seen that we are now at the stage where the data streams, in their various forms, converge into the "box" labelled GIS. Entering this box are "flows" of data - both directly relevant and proxy, as well as the three map "flows" - it is these streams which collectively combine to form the inputs to GIS. In this chapter we intend to show how GISs have evolved, what the major processes are that make up the system, and then to examine something of the technology necessary for making the system function. We also intend to look at benefits and problems of GIS and then to give some guidance on system selection, including the support facilities available. We will conclude by attempting, in this complex and fast changing field, to examine some likely future trends in GIS. A varied selection of functional GISs, as applied to aquaculture, inland fisheries or related topics, are exemplified in Chapter 7.

6.2 Defining GIS

GIS is a branch of science, or a field of learning, which has evolved, and is very much still evolving, at such a rapid pace that a definition of what it is or what it does, has changed and expanded so much that the only thing that we can be certain of is that any definition we give now would not describe what is being done in perhaps 5 or 10 years time ! This rapid evolution, which is described in more detail in section 6.3, has meant that there is much controversy over not only a definition of GIS, but also where GIS lies in a hierarchy of similar fields and on what basis a typology of GIS should be determined.

Though it would appear that the nomenclature of "Geographic(al) Information System(s)" is coming to the fore and is becoming universally accepted as pivotal or central to those processes which we describe in this chapter (Clarke, 1986), there is still a body of opinion which considers GIS to be a "narrow term", only one strand of several systems which, although similar, should retain their separate identities (Shand and Moore, 1989). Other names synonymous with GIS include:

"Geog-based information systems",
"Natural resource information systems",
"Geo-data systems",
"Spatial information systems",
"Geographic data systems",
"Digital mapping systems",
"Land information systems" (LIS).

It is likely that most of these names will give way in favour of GIS, though LIS is likely to hold its ground for a while, along with other associated or specific application areas such as "Computer Aided Drawing" (CAD) and "Automated Mapping/Facilities Management" (AM/FM).

Actual definitions of GIS will be variable and range from the very simple: "A computer system capable of holding and using data describing places on the Earth's surface", through the rather limited: "A GIS then is a software package,....." (Butler, 1988, p.31) and through the novel: "GIS are simultaneously the telescope, the microscope, the computer and the xerox machine of regional analysis and synthesis." (Abler, 1988, p.137), eventually to extremely "wordy" definitions. We would suggest that an actual definition is not as important as the basic ideas which GISs convey, e.g. the essence of GIS must involve:

i) That being "geographical" it contains data and concepts which are concerned with spatial distributions.

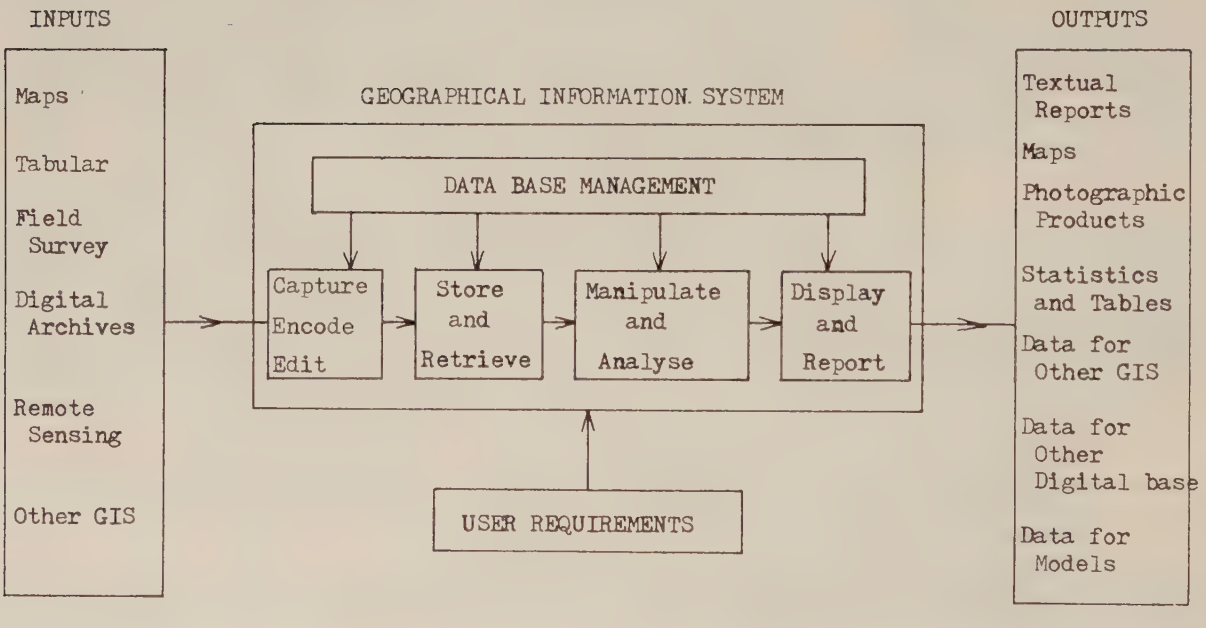
ii) That "information" implies some notion of conveying data, ideas or analyses, usually as an aid to decision-making.

iii) That being a "system" it involves the sequence of inputs, processes and outputs.

iv) That the three strands mentioned above are given functionality within a recent technological scenario based on "Hi-tech" capabilities.

In very practical terms GIS comprise a collection of integrated computer hardware and software which together are used for inputting, storing, manipulating and presenting geographical data (Figure 6.1). The data may be in any textual, map or numeric form which are capable of being integrated within a single system. GIS exist in a variety of forms and embody the potential for an enormous range of applications. No single typology for GISs has yet emerged and clearly a number of categorizations are possible. For those interested we recommend Clarke (1986) and Bracken and Webster (1989).

Figure 6.1 Systems Diagram to Illustrate GIS


INPUTS
Maps
Tabular
Field Survey
Digital Archives
Remote Sensing
Other GIS
GEOGRAPHICAL INFORMATION SYSTEM
DATA BASE MANAGEMENT
Capture Encode Edit
Store and Retrieve
Manipulate and Analyse
Display and Report
USER REQUIREMENTS
OUTPUTS
Textual Reports
Maps
Photographic Products
Statistics and Tables
Data for Other GIS
Data for Other Digital base
Data for Models

6.3 The Evolution of GIS

The rapid evolution of GIS, especially over the last decade, has been caused by a complex amalgam of major factors, plus a number of minor ones. Here we identify the major factors before briefly examining the historical sequence of GIS development. For those interested further in these areas, details are given in Burrough (1986), Jackson and Mason (1986), Dept. of Environment (1987), Smith *et al* (1987), Crosswell and Clark (1988), Goodchild (1988), Tomlinson (1989) and Star and Estes (1990).

6.3.1 Factors Causing the Recent Expansion of GIS

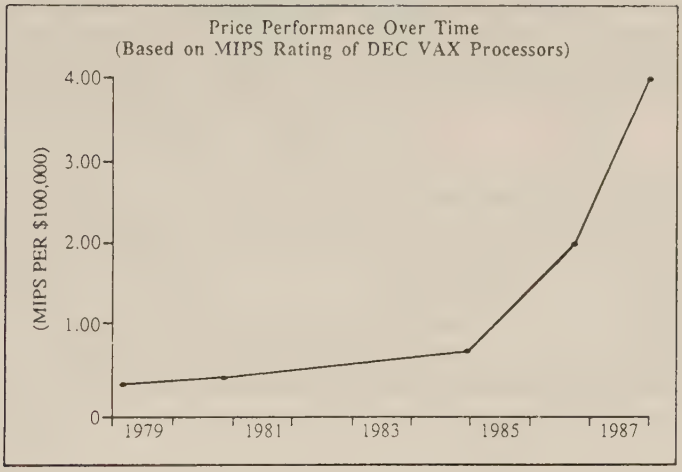
6.3.1.1 The proliferation of data

Over the last two decades there has been a surge in data volume, much of which has been available in digital format, e.g. from RS sources, from censuses and from the major mapping agencies. This surge was in response to the perceived need to have banks of information, in an easily manipulated form, so as to maximize the use of expensively procured data. Much of this data has been accessible using various on-line facilities associated with computer networking and communications.

6.3.1.2 The reduction in computing costs

Technological advances in computer hardware have enabled a dramatic increase in the performance/cost ratio of computer processors. Dept. of Environment (1987) estimates that processing costs have fallen by a factor of 100 in the past decade, and that this is likely to continue. Figure 6.2 illustrates how processor performance has also increased in terms of speed obtained relative to investment made. Performance increases are now tending to blur the traditional distinction between the hierarchy of "mainframe", "minicomputer" and "microcomputer" - a minicomputer does today what only a mainframe could do five years ago. Actual hardware size reduction has allowed for significant office space saving costs.

Figure 6.2 Improvements in Processor Performance Over Time (from Croswell and Clark, 1988)



6.3.1.3 The integration of parallel developments

Advancing on the tide of the explosion in computing power and capability have been a number of parallel developments. These include: computer aided design (CAD), remote sensing (RS), spatial analysis, digital cartography, surveying and geodesy, etc. All these fields have a spatial perspective and can be inter-related, though other fields such as IT, image processing, computer graphics and photogrammetry have also contributed. GIS has emerged as a core methodology allowing for integration to occur if desirable, or allowing for each of the separate fields to greatly enhance their own efficiency. Thus GIS is "...the result of linking parallel developments in many separate spatial data processing disciplines." (Burrough, 1986. p.6), and it allows for some considerable developmental effort and costs to cease being duplicated.

6.3.1.4 Increased opportunities for GIS

Paper maps have traditionally formed the basis of spatial enquiry and these were needed at a large range of scales. Paper maps occupy much space, are easily damaged, they date quickly, they are expensive to produce and data cannot be rapidly extracted from them. The inception of GIS has changed much of this. Both private and governmental organizations have quickly realized the tremendous social, environmental and commercial value of GIS for a range of applications - the main fields are in market location analysis, property management, social resource allocation, resource exploitation, inventory location and environmental analyses.

A consequence of this application and commercialization of GIS has been a proliferation in research and development. GIS has allowed decision makers, in all organizations, to explore a range of possibilities or scenarios before large investments are made or before plans and actions are implemented.

6.3.2 The Historical Development of GIS

Though there have been claims for very early GISs, e.g. the British Domesday Book of the late 11th century, GIS as we recognize it had its origins in the Canadian GIS of 1964. This embodied the early recognition of what might be possible in terms of using computers for handling numerical data and with out-putting useful and timely information. GIS development was limited in the 1960s and early 1970s because of cost and technical limitations, though during this period the development of the minicomputer was important as was the creation of some original mapping packages, e.g. SYMAP, GRID, IMERID and GEOMAP.

During the 1970s there was a rapid rise in the related, parallel fields (section 6.3.1.3). Advantages were seen in linking data sets, utilizing spatial data in more ways and GIS associated equipment was beginning to be acquired by universities, research organizations and small private companies. By the late 1970s computer mapping had made rapid advances. There were hundreds of computer systems for many applications. Interactive capability was achieved and there were great advances in output devices capable of generating high resolution displays and hard copy graphic products. There were also many computer literate students emerging from universities.

In the 1980s GIS had really taken off, especially during the latter part of the decade, and it is now a growth industry of major proportions. We list some of the developments which have occurred recently - further details will occur throughout this chapter:

a) Advances in interactive query and graphics processing.

b) Proliferation of low-cost software, much of it suitable for personal computers (PCs). Improved instructions, menus, manuals, etc. have made GIS accessible to non-GIS specialists.

c) Distributed computing via networks for the sharing of resources and data.

d) The availability of "off-the-shelf" or "turn-key" GIS systems, sometimes comprising complete hardware and software packages.

e) Significant microprocessor developments have allowed for cost reductions and for huge amounts of memory concentration into very small "chips".

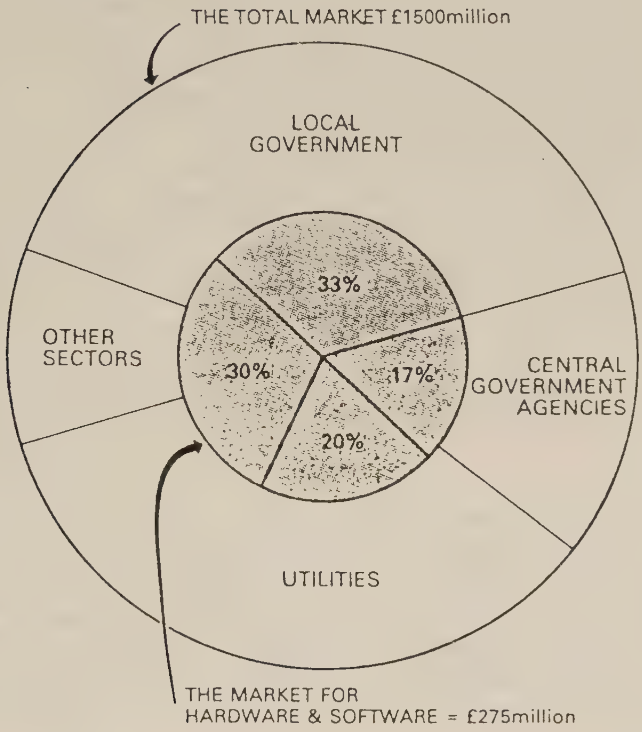
f) A trend from the use of, or digitizing of, specific maps towards having archives of digitized data in a cartographic data bank which can be manipulated, analyzed and displayed in any desirable form.

g) A proliferation in the support side of GIS - journals, courses, education, symposia, etc.

h) Governments, utilities and other enterprises seeking increased efficiency in data handling.

During the whole recent developmental period there has been a "leap-frogging" of developments within specific areas of GIS in terms of them being applications-driven or technology-driven. Most of the developments have been occurring in North America though some have come from Europe. In most countries the government has played a large part in GIS progress since it has been the generator of large volumes of data, since it created needs in departments such as forestry, land use planning and natural resource development and since it is being increasingly called upon to take a leading role with environmental concerns. The global market for GIS systems and data is currently (1990) estimated at $4 billion, and is growing at 20% per annum (Tomlinson, 1989), and Figure 6.3 exemplifies a breakdown of the likely U.K. GIS market till 1999 (Rowley and Gilbert, 1989).

Figure 6.3 The Breakdown of the U.K. GIS Market Till 1999 (from Shand and Moore, 1989)



6.4 The Functioning of GIS

Figure 6.1 showed the overall functioning of GISs in a simplified form. In this section we describe the elements displayed within the GIS "box", and show how they are integrated for the successful functioning of the system. There are a great number of functions which a GIS might be required to perform and the most important of these are set out in Table 6.1. The list is compiled from a variety of sources and the interested reader should consult the following: Knapp and Rider (1979), Rhind (1981), Dangermond (1983), Burrough (1986), Smith *et al* (1987) and Rhind and Green (1988). Throughout this section we will briefly discuss those peripheral hardware items which are directly related to GIS. Space prohibits a review of general computing hardware, e.g. processors, disk drives, alphanumeric terminals, tape drives, V.D.Us and other monitors, even though they may be essential to GIS. In section 6.7 we do look at ways of optimizing hardware systems configurations. Further details on GIS hardware can be obtained from Letcher (1985), Megarry (1985), Walsh (1985), Croswell and Clark (1988), Kadmon (1988) and Dangermond and Morehouse (1989).

Table 6.1 A Classification of GIS Functions

A) DATA INPUT AND ENCODING

i) Data capture, e.g. digitizing and integration of external data.
ii) Data validation and editing, e.g. checking and correction.
iii) Data structuring and storage, e.g. construction of different kinds of surfaces and data coding.

B) DATA MANIPULATION

i) Structure conversion, e.g. conversion from vector to raster.
ii) Geometric conversion, e.g. map registration, scale changes, various transformations, map projection change.
iii) Generalization and classification, e.g. reclassifying data, aggregating or disaggregating data.
iv) Integration, e.g. combining layers of different surfaces.
v) Enhancement, e.g. image edge enhancement.
vi) Abstraction, e.g. calculations of area centroids and Thiessen polygons.

C) DATA RETRIEVAL

i) Selective retrieval of information based on user-defined themes or criteria, including "browse" facilities.

D) DATA ANALYSIS

i) Spatial analysis, e.g. route allocation, slope and aspect calculations.
ii) Statistical analysis, e.g. histograms, frequency analysis, measures of dispersion.
iii) Measurement, e.g. line length, area and volume calculations, distance and directions.

E) DATA DISPLAY

i) Graphical display, e.g. maps, graphs.
ii) Textual display, e.g. report writing, production of tables.

F) DATA BASE MANAGEMENT

i) Support and monitoring of multi-user access to the data base.
ii) Coping with system failures.
iii) Communication linkages with other systems.
iv) Up-dating of data bases.
v) Organization of the data base for efficient storage and retrieval.
vi) Maintenance of data base security and integrity.
vii) Providing a "data-independent" view of the data base.

6.4.1 Data Input and Encoding

All data being input to a GIS must be in digital format, in either numeric or alphanumeric form. Data may be input via a variety of mediums including computer compatible tapes (CCTs), floppy disks, Compact Disc-Read Only Memory optical discs (CR-ROMs), etc. It is obvious that if the data is originating from multifarious sources, then each data set may differ structurally. Given that "The creation of a clean, digital database is a most important and complex task upon which the usefulness of the GIS depends." (Burrough, 1986. p.57), then, from a GIS viewpoint, it would be ideal and far more efficient if data could be:

i) Compatible, i.e. various sets were able to be linked or moved around.
ii) Disaggregated, i.e. so that users could select their own units (or areas) to manipulate or analyze.
iii) Location referenced, i.e. to a National Grid or latitudes and longitudes or to any kind of reference system or to some standard basic spatial unit (BSU) of area.
iv) Accurate - and therefore able to be referenced to the smallest aerial unit possible.

In the absence of this ideal, GIS systems software must either ignore these factors, compensate for them or make do with sub-optimal input levels.

6.4.1.1 Data capture methods and hardware used

The input sources from where the data for GIS may originate have been discussed in Chapters 2 to 5 and are shown in Figure 6.1. In this section we need not discuss inputs from digital archives or inputs from other GISs, since these will both be already available (captured), frequently in a format suitable for immediate use. The choice of other capture methods will be governed largely by the available budget and the type of data being input. The methods of capture for data sources are:

A) *For Tabular and Field Surveys*

Capture may be by using manual methods, aided by a keyboard and VDU, to interactively create data bases or files, i.e. for entering the results of field work or questionnaire surveys. Data might be filed in either a standard spreadsheet package or in any of the many specialist data entry modules associated with particular computer packages or programs, e.g. statistical packages such as SPSS or Minitab, computer cartography packages such as MICROMAP or survey analysis packages such as SNAP. These programs or packages require that data is entered in a structured format - the data can then be edited and corrected and any numerical manipulations can be performed.

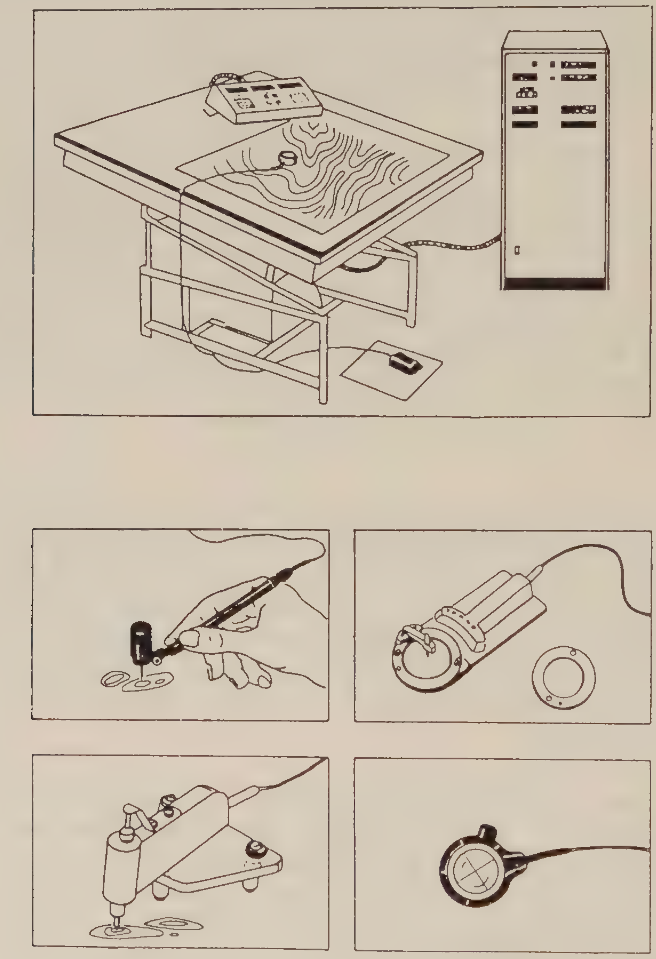
Data loggers can be used. These are specialist devices that automate the process of collecting and recording data in the field. They may be automatic or semiautomatic. They carry out a limited range of functions recording data on variables such as soil moisture content, water flow, sediment particle size, climatic variables, etc. For analogue data loggers, the data will need to be digitized. Specialist data entry devices are available which semi-automate the field collection of live questionnaire data, i.e. answers are fed directly into a pre-programmed memory within a battery operated, hand held portable terminal. There are a variety of other microcomputers which are now becoming available as a result of microprocessor advances and subsequent price reductions. Maguire (1989) provides further useful information on many field data capture methods.

B) *For Map Data*

Maps may be captured by the use of digitizers or various types of scanners, e.g.:

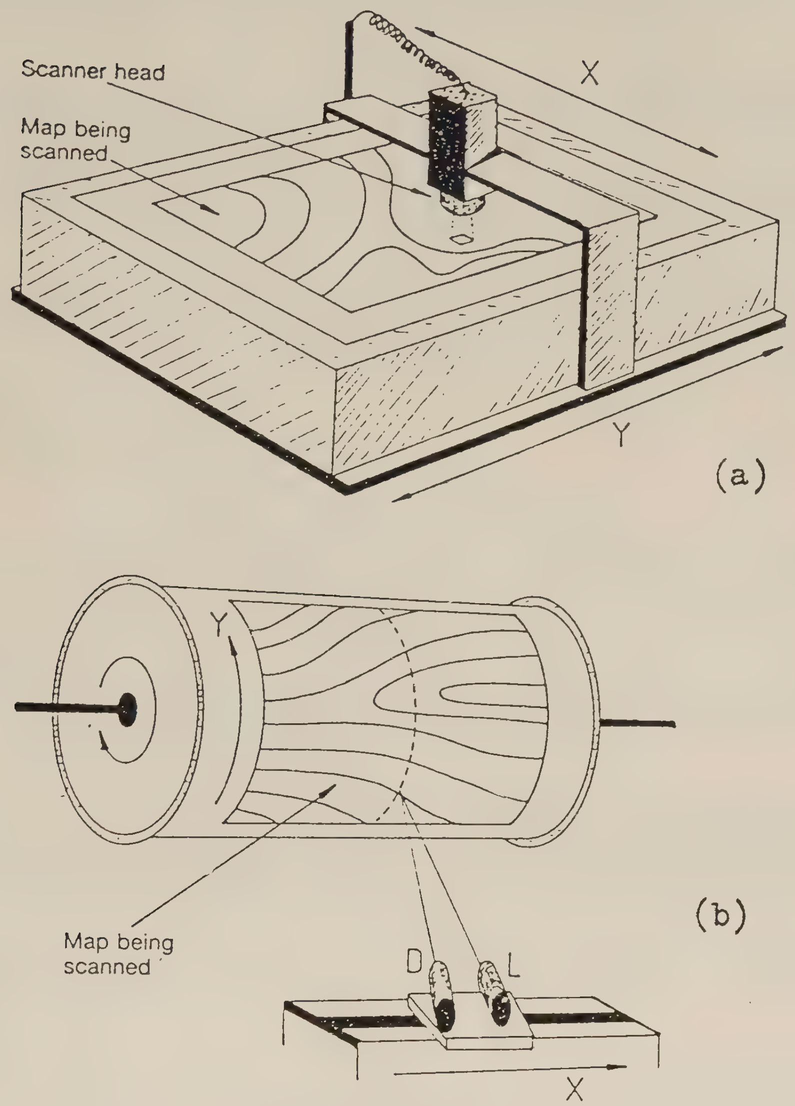
i) Electromechanical digitizing involves using a tiltable table, or tablet, on which the map is positioned (Figure 6.4), with an in-built Cartesian surface (grid), having energized intersections typically resolving to 0.01mm. Attached to the table is a pen or tracking cross (cursor or puck) which can be moved along lines or to points, and can detect the signal at any intersection of the grid. Cursors can be equipped with up to 16 buttons which are used for additional program control, e.g. to move from point to line or for adding identifier labels. The analogue signal detected is coded by the computer into a digital x,y co-ordinate, measured from a user-defined origin. These digitizers may work in either point or line/stream mode. In the former points are recorded at a signal from the operator; in the latter mode the digitizer records co-ordinates at fixed time or distance intervals. Some digitizers can operate in all three modes. Digitizers are increasingly linked directly to VDUs for monitoring purposes, and/or linked to the host computer for direct input of data and to allow the computer to set up the digitizing operating parameters.

Figure 6.4 An Electro-Mechanical Digitizer plus Various Types of Line-Following Cursors (from Kadmon, 1988)



ii) In flat bed optical scanning the scanning head moves along both the x and y axis (Figure 6.5 (a)). Drum scanning involves using a scanning densitometer. A map is fixed to a rotating drum and a scanning photosensitive cell moves backwards and forwards along the x axis capturing, in digitized form, the image of the map as a matrix of pixels (Figure 6.5 (b)). Pixel values vary with differences in light intensity. The step size between each row controls the cell or pixel size in both scanners - this is very small in modern scanners. Scanners are now available for vector (line) scanning - here a laser beam automatically follows lines until junctions are reached or until the user selects alternative lines. With this scanner great accuracy can be achieved but it is user/time intensive. The problem of automatically scanning colour maps is overcome by scanning the colour print masters which are usually black and white thematic lithographs. Scanners have a typical resolution of up to 0.012mm and can collect data at the rate of 30 000 pixels per second.

Figure 6.5 Flat Bed and Drum Optical Scanners (from Burrough, 1986)



iii) In electronic videodigitizing a video camera captures images as collections of up to 512 x 512 pixels each containing a level of light intensity. They are useful for capturing line boundaries from RS or aerial images and entering them into image analysis systems. This is a cheaper form of map capture than scanning, but the resolution is poor.

Data capture from maps is usually by layers, with each layer representing a different theme (Figure 6.6). Capture in this form permits easy updating and specific spatial analyses. Digitizers can input grid-based or vector-based data (section 6.4.1.2) plus textual map labels or special symbols. Most digitizing is carried out off-line using a separate microcomputer or PC for job control or data storage. Attribute data is usually entered from a keyboard. Common problems associated with digitizing are:

i) It can be very time consuming if done accurately, e.g. it takes about 30 person hours to digitize the boundaries of a typical 60 x 40cm soil map at 1:50 000. Digitizing costs can form a very high proportion of GIS costings, and scanners are an expensive alternative.

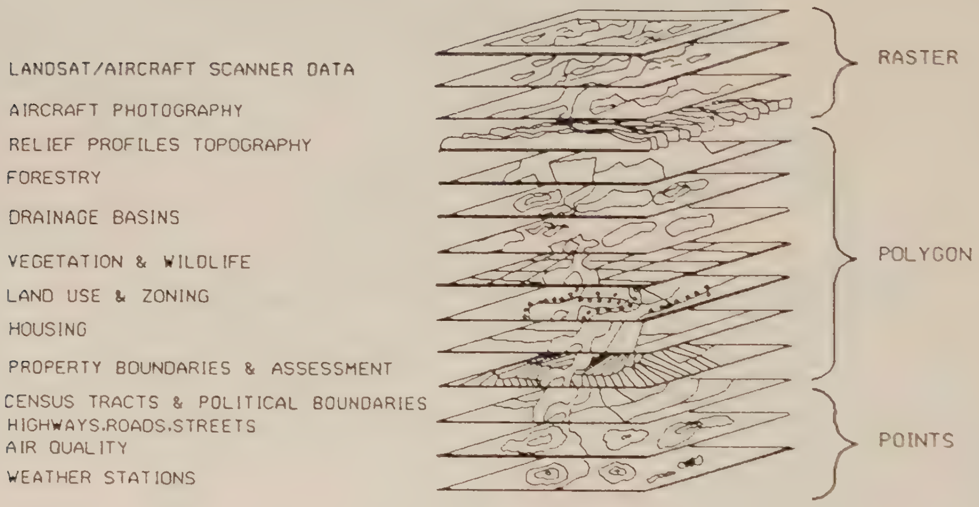
ii) Huge data files can be created from single map sheets.

iii) Automatic scanners are frequently unreliable where several lines are in close proximity, e.g. contours in mountainous areas.

iv) Manual digitizer operators can only work for approximately four hours daily if accuracy is to be maintained.

Since most new maps series are now produced using digitizing methods, some of the problems associated with digitizing will ease once the pressures to digitize existing sheets have been dealt with.

Figure 6.6 Representation of the Layers Captured by RS or Map Digitizing (from Goodenough, 1988)


LANDSAT/AIRCRAFT SCANNER DATA
AIRCRAFT PHOTOGRAPHY
RELIEF PROFILES TOPOGRAPHY
FORESTRY
DRAINAGE BASINS
VEGETATION & WILDLIFE
LAND USE & ZONING
HOUSING
PROPERTY BOUNDARIES & ASSESSMENT
CENSUS TRACTS & POLITICAL BOUNDARIES
HIGHWAYS,ROADS,STREETS
AIR QUALITY
WEATHER STATIONS
RASTER
POLYGON
POINTS

C) *For the Integration of Remote Sensing into GIS*

Space precludes much discussion of the procedures necessary for the integration of RS imagery into GIS - Jensen (1986) and Goodenough (1988) provide more detail on this. Here we will mostly concentrate on some precautionary advice.

We have shown, in section 4.6, that RS imagery is preprocessed to a variety of user-defined levels, and then filed on CCTs. This data can then be integrated into the GIS, perhaps via external packages such as ERDAS or GEMS, which have been used to perform additional processing. Some GIS software contains its own RS processing programs. The most important task in integration is ensuring that RS-derived data is referenced to exact ground co-ordinates so that registration with other GIS data is possible.

Before integrating the RS data (being held on a CCT) it is important to know the levels of pre-processing which may have been performed. If only crude radiometric and geometric corrections have been done then any of the further pre-processing levels described in section 4.6 might be necessary. Actual integration may give rise to a number of problems. The RS data may only be classified into 256 class levels, whereas GIS are capable of handling far larger arrays. This may make it difficult to assign detectable RS image features to classes in the GIS. There is inevitably difficulty in matching RS images to other thematic data which has been derived from topographic map sources or elsewhere - this is especially true in areas having varied relief. Goodenough (1988) found that it was not uncommon to have displacements of 200 meters at the 1:50 000 scale. Other problems include differences in land area shapes and sizes as well as the image interpretation problems described in Chapter 4.

Some authors argue that there has been very little success in integrating RS into GIS. Young and Green (1987) say generally that this is because of differences between the potential and the operational realization of this potential, and more specifically Wilkinson and Fisher (1987) note that too much RS data is available at a resolution which is not reliable for realistic GIS. Robinson Barker (1988) puts the lack of success down to a cooling off from an initial period of great interest in the mid-1970s and to government indecision and inaction. There was also "too much technology and data" and very sophisticated techniques were needed so that even now low cost interactive RS data does not exist. Finally, RS data is in gridded (raster) format whilst the majority of GIS work in vector format. It is important to bring attention to these limitations, not only to warn the potential user, but also to show that there is still a huge amount of research necessary to ensure reliable integration, and it could well be that the future of RS depends upon its ability to integrate successfully with GIS.

6.4.1.2 The structure of spatial data

A bird's eye view of the world, as depicted on a mapped surface, reveals that the surface consists of either points, lines or 2D areas which are cartographically called polygons. Thus in Figure 6.7 (a) roads would be lines, houses are usually points and gardens or fields are polygons. All information captured by any method shown in section 6.4.1.1 must be capable of being displayed, and therefore must be appropriately encoded to show any of these three forms. There are two basic organizational modes which the computer may work in to display spatial forms, i.e. vector or raster mode (respectively (b) and (c) in Figure 6.7).

A) *Vector Mode.* Here a map will consist of points whose positions are defined by geographic x,y co-ordinates. A point may be defined in isolation to represent a single relatively small mapped object such as a telephone box, a building or a settlement, i.e. depending on the scale of the map. A series of points can be defined and joined to show a line - this might represent a field boundary, road, river, etc. Lines too can be defined and joined so as to enclose an area (a polygon) which might represent any 2D feature such as a field, lake or a country or any thematic area such as an individual soil zone.

Digitizing in the vector mode can be extremely accurate, e.g. in representing non-straight lines additional accuracy is obtained by registering (digitizing) a larger number of points around a curve. The vector mode is usually employed where it is necessary to integrate manual and computer graphics techniques and where annotations are frequently required. Because vector modes use quite complex data structures, the technology is expensive as is display and plotting, particularly for high quality colour products.

B) *Raster Mode.* Here the whole mapped surface is composed of a grid of cells which form a matrix of rows and columns. The size of each cell determines the resolution (or detail) of the mapped surface. Very small cells are referred to as pixels (as in RS imaging), and each cell or pixel is a data element showing, by digital encoding or by colour coding of the final map, the occurrence of different features at different cell locations.

Raster graphics are usually used where it is necessary to integrate topographical and thematic map data, either together or with RS data. The main problem of this mode is that the use of cells means that recognizable structures can be lost and there can be a serious loss of information. However, each of the two modes will have several advantages over the other (Table 6.2) and this means that they are best seen as complementary rather than competitive. Though in some ways the issue of structure mode is critical, because once established it is difficult to change it, GIS are increasingly able to handle data in both vector and raster structure since conversion programmes are now available.

Figure 6.7 Modes of Organizing Mapped Data (from Maguire, 1989)

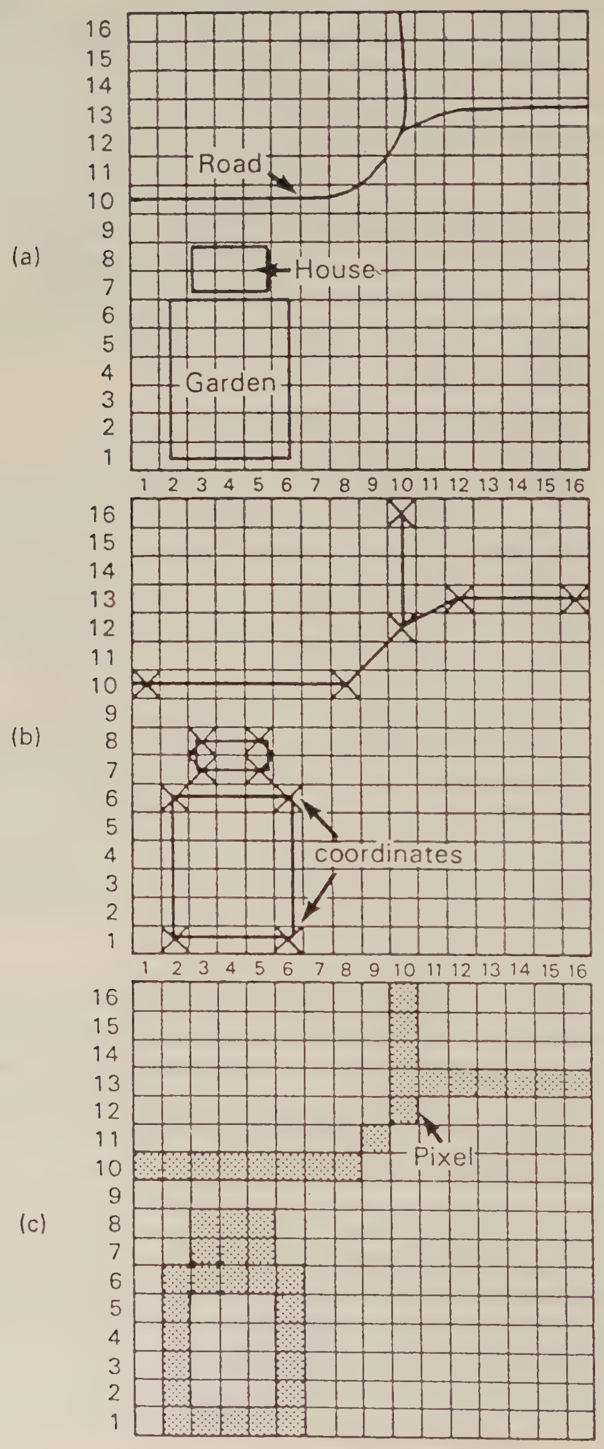

(a)
Road
House
Garden
(b)
coordinates
(c)
Pixel
16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Table 6.2 Main Advantages of Vector or Raster Graphical Forms

VECTOR MODE

i) Features can be accurately located.
ii) Very small features can be shown.
iii) The correct shape of features can be shown.
iv) Total data storage requirements can be far less.
v) Data on individual resources is easily retrieved, updated or annotated.

RASTER MODE

i) Comparisons of different themes (layers) are easy to make.
ii) Quantification and aerial measurements are easy.
iii) Integration of RS, or other grid based imagery, can be efficient.
iv) The data structure is very simple.
v) The technology is cheap and it therefore gains a larger market.
vi) Processing algorithms are simple and easy to write.
vii) Grided data is more compatible with raster based output devices.

6.4.1.3 Linking spatial and non-spatial data

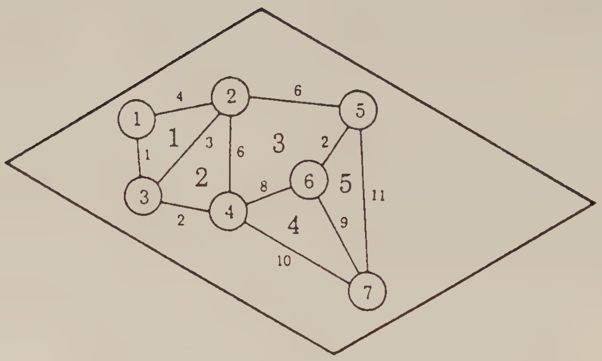
For complete data capture it will be insufficient to simply digitize, in vector or raster format, the graphical data shown on a map or a similar type of data recorded from another source. All spatial data should also have specified:

i) Its location reference.
ii) A feature code, label or attribute saying what it is.
iii) A topological reference used to identify relationships between lines, points and polygons on a map.

Data on each of these need to be digitized in such a format that they can be efficiently attached (linked) to graphical mapped entities.

The actual location reference will be automatically registered via the Cartesian wire grid embedded in the digitizing table or tablet. Data about attributes such as the width of a river, its water quality, the variability of flow, etc., needs to be stored apart from the spatial data, usually in a tabular database. This is done by giving each type of data a common identifier which can be efficiently linked as required, i.e. by using a special computer programme into which the x,y co-ordinates have also been stored. Figure 6.8 shows how topological referencing is rather similarly achieved. Thus a typical polygon map is abstracted into seven nodes (points), eleven links (lines) and five polygons. By the use of the unique identifiers, the spatial relationship between these three possible forms used on maps can readily be tabulated as shown, and by adding x,y co-ordinates at each of the points a dual system of spatially identifying map elements is achieved. Topology is implicit in raster modes because all locations are simply defined by rows and columns.

Figure 6.8 The Creation of a Topological Data Structure (after Dangermond, 1983)



LINK #	RIGHT POLYGON	LEFT POLYGON	NODE 1	NODE 2
1	1	0	3	1
2	2	0	4	3
3	2	1	3	2
4	1	0	1	2
5	3	2	4	2
6	3	0	2	5
7	3	3	5	6
8	4	3	6	4
9	5	4	7	6
10	4	0	7	4
11	5	0	5	7

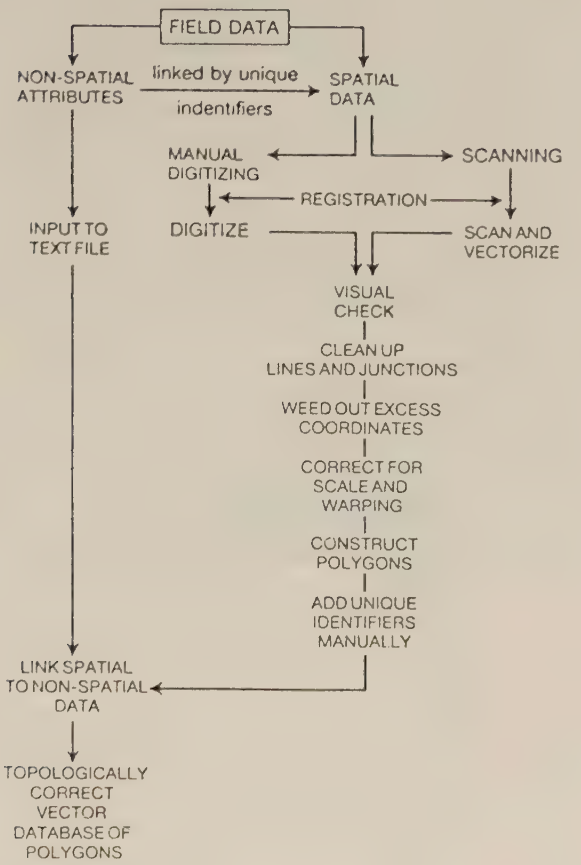
TOPOLOGICALLY CODED NETWORK & POLYGON FILE

NODE #	X COORDINATE	Y COORDINATE
1	23	8
2	17	17
3	29	15
4	26	21
5	8	26
6	22	30
7	24	38

X, Y COORDINATE NODE FILE

Figure 6.9 summarizes the steps needed to digitize a set of boundaries, and their non-spatial attributes, and link them together to form a topologically linked data base of individual polygons. The particular steps might vary according to the GIS being used, volume of data, hardware available, etc. Once the linking of spatial and non-spatial data has occurred, then verification and editing is easily performed.

Figure 6.9 **Steps in Creating a Topologically Correct Vector Polygon Data base (from Burrough, 1986)**

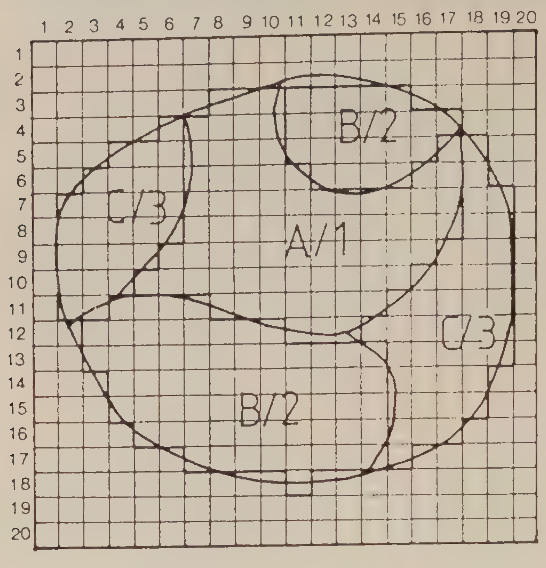

FIELD DATA
NON-SPATIAL ATTRIBUTES
linked by unique indentifiers
SPATIAL DATA
MANUAL DIGITIZING
SCANNING
REGISTRATION
INPUT TO TEXT FILE
DIGITIZE
SCAN AND VECTORIZE
VISUAL CHECK
CLEAN UP LINES AND JUNCTIONS
WEED OUT EXCESS COORDINATES
CORRECT FOR SCALE AND WARPING
CONSTRUCT POLYGONS
ADD UNIQUE IDENTIFIERS MANUALLY
LINK SPATIAL TO NON-SPATIAL DATA
TOPOLOGICALLY CORRECT VECTOR DATABASE OF POLYGONS

6.4.1.4 Efficient data storage structures

It has been intimated that data capture processes are likely to generate huge quantities of digital data. If the computer memory is large enough this might not provide handling problems, but for any smaller microprocessor then greater efficiency can be achieved by selectively storing (compressing) only relevant bits of the data. Space prohibits a detailed discussion of the many types of storage structures - those interested should consult Samet (1984), Jackson and Mason (1986) or Green and Rhind (1986). We briefly illustrate two simple methods:

A) *Run length coding*. This relies on the fact that for many kinds of thematic map, adjacent cells could have the same value. Consequently, it is only necessary to enter the data for each row (run), specifying a cell value and the column numbers where that value begins and ends. For example, Figure 6.10 shows how a simple vector map (a) is converted into a raster cell matrix (b), having encoded digital scores, and (c) shows its final conversion to a run length code. Each "run" is shown by a triplet of numbers indicating starting column, end column and value. In this example a digital saving of nearly 40% has been achieved; further savings could have been made if all "empty" areas were assumed to be zero.

Figure 6.10 Example of a Run Length Code Structure (from Burrough, 1986)



(a)

	Column																			
Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1	1	1	2	2	2	2	2	0	0	0	0	0
4	0	0	0	0	0	3	1	1	1	1	2	2	2	2	2	2	2	0	0	0
5	0	0	0	3	3	3	1	1	1	1	2	2	2	2	2	2	1	3	0	0
6	0	0	3	3	3	3	1	1	1	1	1	2	2	2	2	1	1	3	0	0
7	0	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	3	3	0
8	0	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	3	3	0
9	0	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	3	3	3	0
10	0	3	3	3	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	0
11	0	3	3	2	2	2	2	1	1	1	1	1	1	1	3	3	3	3	3	0
12	0	0	2	2	2	2	2	2	2	2	1	1	1	3	3	3	3	3	3	0
13	0	0	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	0
14	0	0	0	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	0	0
15	0	0	0	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	0	0
16	0	0	0	0	2	2	2	2	2	2	2	2	2	2	3	3	3	0	0	0
17	0	0	0	0	0	0	2	2	2	2	2	2	2	2	3	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

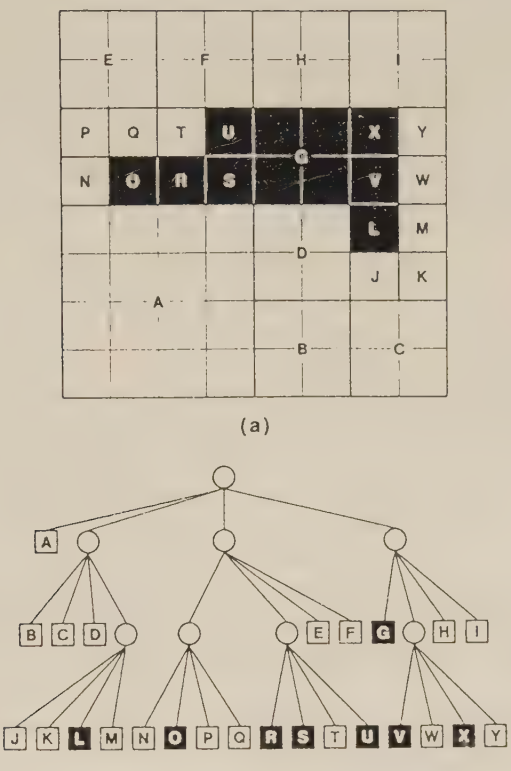
(b)

Row	Column ranges (from, to, value)					
1	1,20,0					
2	1,20,0					
3	1, 7,0	8,10,1	11,15,2	16,20,0		
4	1, 5,0	6, 6,3	7,10,1	11,17,2	18,20,0	
5	1, 3,0	4, 6,3	7,10,1	11,16,2	17,17,1	18,18,3	19,20,0
6	1, 2,0	3, 6,3	7,11,1	12,15,2	16,17,1	18,18,3	19,20,0
7	1, 1,0	2, 6,3	7,17,1	18,19,3	20,20,0		
8	1, 1,0	2, 6,3	7,17,1	18,19,3	20,20,0		
9	1, 1,0	2, 5,3	6,16,1	17,19,3	20,20,0		
10	1, 1,0	2, 4,3	5,15,1	16,19,3	20,20,0		
11	1, 1,0	2, 3,3	4, 7,2	8,14,1	15,19,3	20,20,0	
12	1, 2,0	3,10,2	11,13,1	14,19,3	20,20,0		
13	1, 2,0	3,14,2	15,19,3	20,20,0			
14	1, 3,0	4,14,2	15,18,3	19,20,0			
15	1, 3,0	4,14,2	15,18,3	19,20,0			
16	1, 4,0	5,14,2	15,17,3	18,20,0			
17	1, 6,0	7,14,2	15,15,3	16,20,0			
18	1,10,0	11,11,2		12,20,0			
19	1,20,0						
20	1,20,0						

(c)

B) *Quadtrees*. This is a data structure based on the regular decomposition of a region into quadrants and sub-quadrants. Eventually the whole of a specified functional category within a gridded area will be delineated by cells of varying sizes, i.e. down to the smallest pixel for which data has been gathered (Figure 6.11). The relationship between the raster map, with its sub-divided cells, can be shown as links and nodes in a "directed tree", with each link being directed from the "parent" node towards its "children" (sub-quadrants). From each node in the tree there are four "edges" representing the four quadrants of N.W., N.E., S.W. and S.E. Sub-quadrants only emanate from nodes which are shown as being sub-divided in the raster map. From the example shown it can be seen that nearly a 50% saving in data capture has been made.

Figure 6.11 A Raster Mode Map and Its Quadtree Representation (from Jackson and Mason, 1986)



(a)

(b)

6.4.2 Data Manipulation

Once data has been captured, the data base files reside in CPU memory (RAM) and are thus immediately accessible for computation and manipulation. Because of the large amount of data in the files, they are usually stored on fast hard disk drives. Sometimes data may be stored off-line on magnetic tape or other media, e.g. floppy disks. To extract meaningful information from the data base, it will need to be queried, organized and perhaps changed in any number of ways to suit individual requirements, i.e. manipulated so that it can be retrieved in a useful format for later analysis. The distinctions between data capture, manipulation and data analysis are not hard and fast - they are all functions performed within the GIS and there is a considerable degree of overlap. The main data manipulative functions will be briefly examined, i.e. those that most GIS software will be programmed to perform - further information can be obtained from Berry and Tomlin (1981), Dangermond (1983) and Burrough (1986) and selected case studies will be provided in Chapter 7.

6.4.2.1 Data validation, correction and editing

These functions are usually performed on the initial data soon after capture, though they might be necessary at any stage. All captured data must be interactively reviewed for errors, since these are common, especially in digitizing. Typical digitizing errors are:

i) "Double digitizing" - lines are digitized twice which introduces "slivers" into the data if the lines do not exactly correspond.

ii) "Undershoots" or "overshoots", where lines are either too long or too short.

iii) Lines, line segments (arcs) or points may be entirely missing.

All errors require correction or editing. Some GIS software contains programmes for verifying the correctness of all geometric, topological and attribute data. This might involve making certain that all graphical data is suitably defined; that spatial attributes do not exceed expected ranges or values; that nonsensical combinations of attributes do not occur, etc. The importance of error correction cannot be overstated. Burrough (1986) devotes 30 pages to a detailed analysis of error propagation and Goodchild and Gopal (1989) write exclusively about the needs for spatial accuracy. If data is not scrupulously verified, and errors remain captured, then further manipulation of the data will lead to error magnification and the subsequent invalidity of the data.

6.4.2.2 Structure conversion

We have previously mentioned (section 6.4.1.4) that data can be structurally converted so as to require less storage. The other main structural conversion which may be necessary is raster to vector conversion or vice versa. Figure 6.12 gives a simple illustration of what is involved. Note that in the vector to raster conversion a loss of accuracy is incurred, which can be magnified as a function of both cell size and "wiggliness" of the lines. In the raster to vector conversion, the computer performs a vectorizing process which consists of "threading" a line through a swarm of pixels, using a "thinning" algorithm (because the swarms of pixels are thinned to a line).

6.4.2.3 Geometric conversion, map sheet manipulations or transformations

This heading covers several forms of manipulation all aimed at geometrically changing the mapped surface so that maps can be adjusted to one another, or to a reference system (Figure 6.13). Different algorithms will need adopting to facilitate the necessary changes.

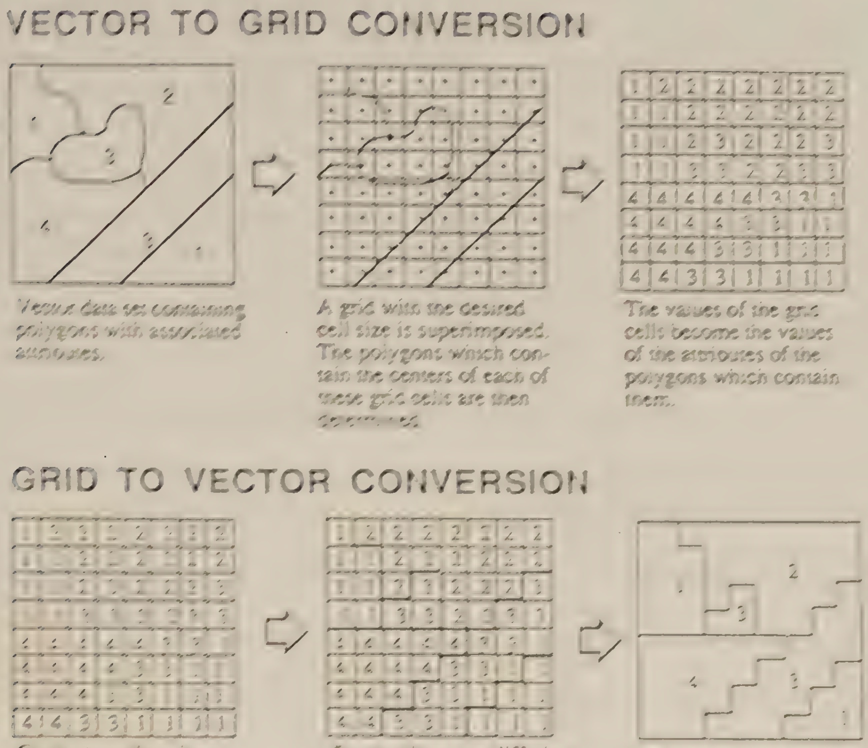
i) Transformations from one co-ordinate system to another, or from one map projection to another.

ii) Scale changes can be adopted by selecting a simple multiplier function.

iii) Maps can be rotated to particular orientations.

iv) Spatial data may suffer from various distortions, e.g. aerial photographs are not always scale correct because of aircraft tilt, relief differences and differences caused by the angle of view, and paper maps will suffer from paper stretch. These distortions (or "image warps") can be manipulated by "rubber sheeting", i.e. treating the distorted image as an elastic sheet which may be stretched or compressed until it exactly fits an accurate base map.

Figure 6.12 Summary of a Vector to Raster - Raster to Vector Conversion (from Robinson Barker, 1988)


VECTOR TO GRID CONVERSION

Vector data set containing polygons with associated attributes.

A grid with the desired cell size is superimposed. The polygons which contain the centers of each of these grid cells are then determined.

The values of the grid cells become the values of the attributes of the polygons which contain them.

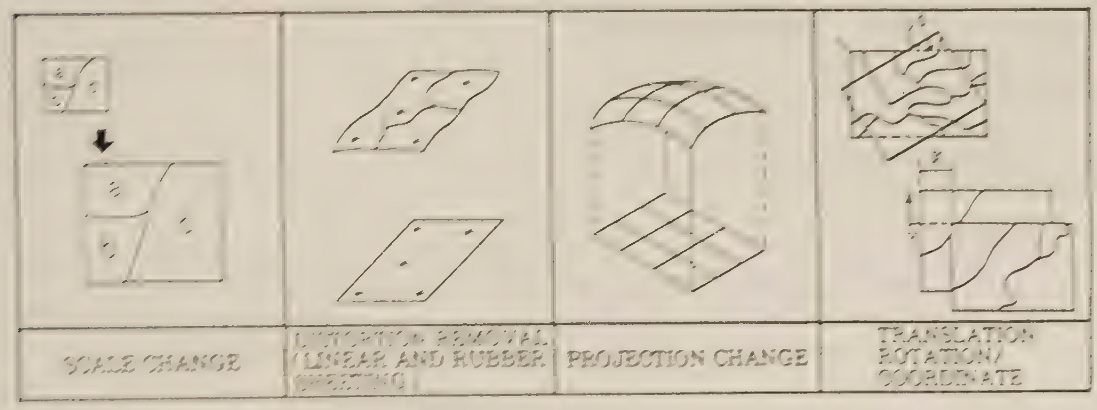
GRID TO VECTOR CONVERSION

Gridded satellite classification with class numbers contained each grid cell.

Borders between differing class numbers are located.

Polygons are then generated for each contiguous area by storing the x, y coordinates of the points along these borders.

Figure 6.13 Some Fundamental Geometric Manipulations of GIS Database Files (after Dangermond, 1983)

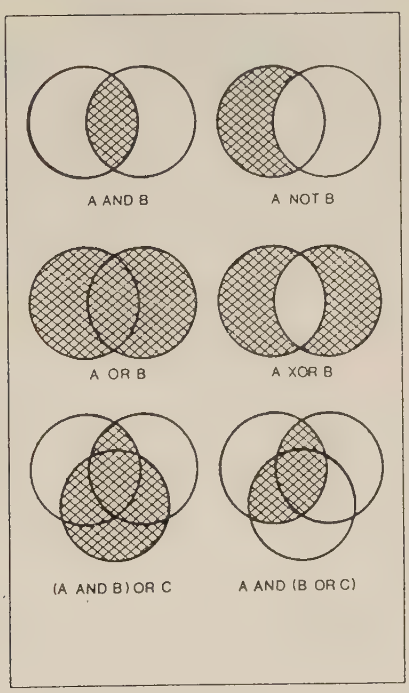

SCALE CHANGE
DISTORTION REMOVAL (LINEAR AND RUBBER SHEETING)
PROJECTION CHANGE
TRANSLATION ROTATION/ COORDINATE

6.4.3 Data Retrieval

This is a crucial component of GIS since it greatly affects the users ability to interact with the data, and the way the user is able to restructure the data to solve specific problems. Many variations of the data will be retrievable, e.g. by specified area or region, theme or class, etc., and these may be retrievable in different ways using two separate retrieval systems - one for map data (lines, points, polygons), and one for non-map data (attributes, etc.).

As well as simple searching and retrieval by theme or area, retrieval using the rules of Boolean Logic is commonly employed. Here the simple operators of "AND", "OR", "XOR", "NOT" are stated to see whether a particular condition is true or false. This can be portrayed in the form of Venn diagrams (Figure 6.14). Commands can be input to the GIS such that any combinations of attributes for a theme or an area can be retrieved or any combination of spatial areas. For example, a command could read "find all water bodies with a mean average temperature of >20C, in combination with a pH of >7.0, that exceed 3ha in area". Complex retrieval commands could involve aerial shapes, lengths of waterway, intensity of current fishing levels, adjacency to urban areas, etc.

Figure 6.14 Venn Diagrams to Show the Results of Applying Boolean Logic to Two or More Sets (from Burrough, 1986)

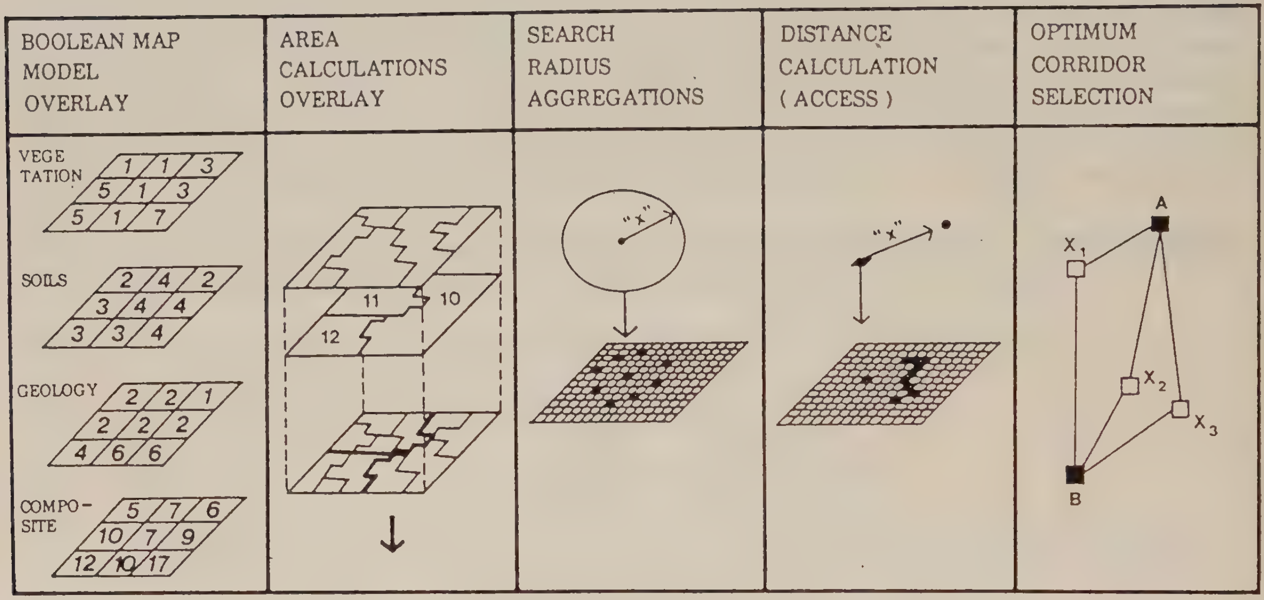


Retrieval for analytical purposes would normally be done interactively. As well as the previously mentioned zooming and windowing facilities, retrieval functions usually have browse or search facilities.

6.4.4 Data Analysis

GIS provide a large range of analysis capabilities that can operate on selected spatial aspects of the data, the non-spatial attributes of those data or on a combination of these. The user will work interactively to perform the analyses. In Table 6.1 we classified data analysis under three categories - spatial, statistical and measurement. These headings are arbitrary and other classifications could be used, e.g. Dangermond (1983) and Jensen (1986) differentiate between polygon-based and grid cell-based analyses noting that, although grid cell analyses are more generalized, they are much more efficient in terms of data storage and in the operation of analytical tasks. Figure 6.15 exemplifies some grid-based analytical techniques. Because there are so many analysis types, we will simply list some of the more common ones.

Figure 6.15 Some Grid-Based Analytical Techniques (after Dangermond, 1983)


BOOLEAN MAP MODEL OVERLAY
AREA CALCULATIONS OVERLAY
SEARCH RADIUS AGGREGATIONS
DISTANCE CALCULATION (ACCESS)
OPTIMUM CORRIDOR SELECTION
VEGE TATION
1 1 3
5 1 3
5 1 7
SOILS
2 4 2
3 4 4
3 3 4
GEOLOGY
2 2 1
2 2 2
4 6 6
COMPO- SITE
5 7 6
10 7 9
12 10 17
11
10
12
"x"
"x"
A
X1
X2
X3
B

A) *Spatial Analyses.* As well as the integration and merging of overlays to produce new mapped surfaces for analysis, other spatial analyses include optimizing route allocations (network analysis), calculating intervisibility, slope and aspect, plus digital terrain modelling, location-allocation optimization, trend surface analysis, etc. For most of these spatial analyses raster-based format is optimal, though rapid advances in software programming is likely to soon mean that data structure differences are irrelevant.

B) *Statistical Analyses.* These may range from summarizing and describing simple numerical data, e.g. calculating means, modes, medians, etc., to more complex frequency analysis, measures of dispersion, e.g. auto-spatial correlations, rank correlations and nearest neighbour analysis plus multivariate analyses.

C) *Measurement.* This includes a number of operations which may be carried out on one or more data layers. Examples include the simple enumerating of features (either in total or per polygon), measuring linear or curvilinear distances between or along objects, calculating areas, perimeters or volumes, calculating angles and recording direction measurements. From fairly simple measurements rather more sophisticated data can be derived, e.g. frequency/accessibility surfaces, various cost surfaces and any user-defined matrix analysis.

6.4.5 Data Display

Here we will be concerned both with the types of display and the main devices used for capturing displays. If GIS is thought of as a true processing system then display represents the output from the system. However, unlike most systems where output represents the final processing stage, in GIS output (or display) can be achieved during any of the functional stages listed in Table 6.1. This facility is most important since it allows for user control, review, experimentation, etc. at any stage. Most good GIS software has a range of graphic display features which allows control of label size and fonts, shading ranges, line widths, graphic symbolism, map feature position or composition, etc.

6.4.5.1 Types of display

Output can be in three main forms:

A) *Temporary Display.* This is that which is captured on the visual display unit (VDU). It is the functional user interface in that a visual display is shown of any action that the user takes, and it allows for interactive experimentation or manipulation at no material cost, at great speed and in an almost infinite variety of ways. Before final displays to other output devices, it is important that the prospective output is reviewed and is graphically refined in order to produce meaningful and presentable displays.

B) *Hard-Copy Display.* This is the output which is printed, via a variety of printers and plotters, onto paper or film. Hard copy displays can be in black and white or multi-coloured. The vast qualitative range achievable is dependent upon either cost factors, associated with achievable graphic quality of the hardware used, or with purpose factors related to the intended use of the output. The best quality achievable is now superior to that achieved by manual methods - this qualitative ability has been achieved because GIS functioning has been able to combine and absorb skills from the computer graphics and automated cartography fields.

C) *Disk Files.* These are useful if new data structures resulting from transformation and manipulation processes need to be permanently saved, i.e. for rapid later retrieval or for transfer to another data base, another package or to a separate GIS.

There is a variety of visual formats that the display can take.

Thus graphical displays will consist of an infinite variety of maps or graphs, whilst textual output will include both tables and automatic report writing on data base contents to standard summary sheets.

6.4.5.2 Devices used for capturing display

For the permanent capture of GIS output, there are a huge range of plotters and printers plus associated devices, each of which have their own uses and advantages.

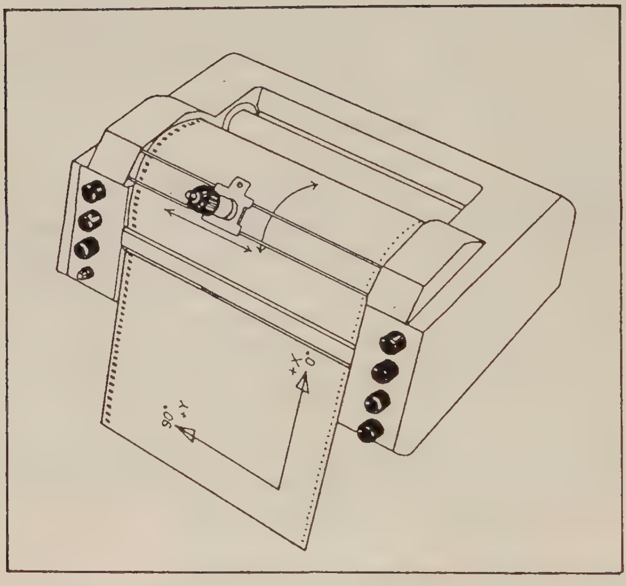
A) *Lineprinters.* Using varying combinations of alphanumeric characters to produce different shadings, lineprinters were an early output device, though they are still frequently used because they are convenient for researchers or cartographers in giving inexpensive previews before subsequently using high quality graphic output. Since lineprinters can only print sequentially, data must be organized by using a suitable software program. The quality of output can be greatly improved by photographic size reduction.

A more recent advance on conventional lineprinting is by the use of the dot-matrix printer/plotter. Here displays are produced as series of dots, with shading varying with dot density, and lines are represented by strings of dots (e.g. Figure 6.19). Alphanumeric or special characters can also be printed.

B) *Wide Format and Ink Jet Printers.* These are becoming state-of-the-art for hard-copy printing. Both types allow for printing high quality text and graphics at high speeds, and they are capable of producing hard-copy output in colour. They are both expensive but require little attention and can be set to run overnight.

C) *Drum Plotters.* These consist of a drum which can be rotated in both directions whilst driving a continuous roll of paper. A pen on a carriage can move along the drum to plot lines (Figure 6.16). All movement is controlled by the computer. Drum plotters work relatively quickly at typical speeds of 40 cms per second. They vary in width from 25cms to 150cms and they can produce multi-colour, high quality output.

Figure 6.16 The Operation and Rotation of a Drum Plotter (from Kadmon, 1988)



D) *Flatbed Plotters.* A drawing pen(s) can be moved over a flat drawing surface in both x and y directions, or in conjunction to produce curved lines (Figure 6.17). The movements will correspond to grid co-ordinates held in a computer file. Flatbed plotters typically have A3 or A4 plotting areas, facilities for multi-colour plotting and work at speeds of about 25cms per second. They have a number of advantages over other plotters:

i) Some can be used as digitizers.

ii) They can use various forms of writing, scribing or laser implements, on drawing paper, acetate and lithographic film.

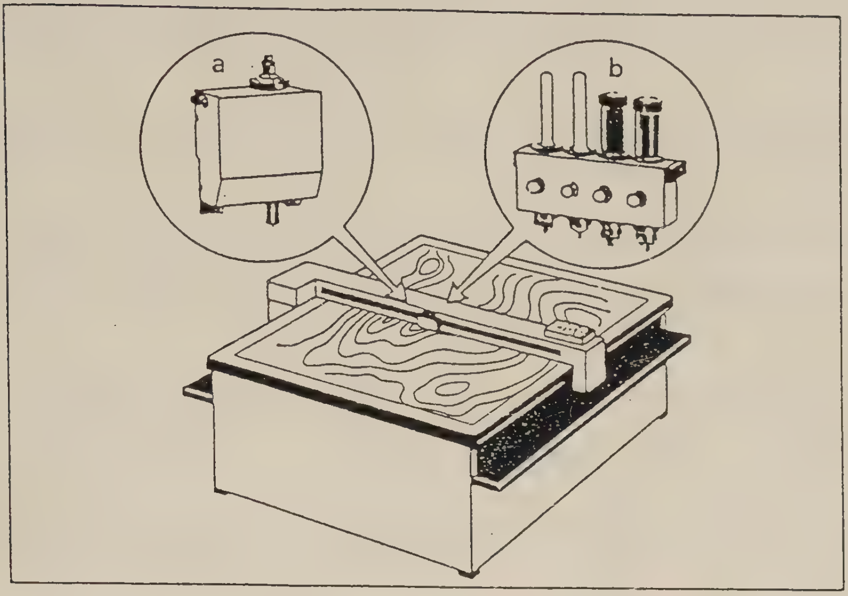
iii) They are heavy and stable giving greater precision.

iv) A large variety are available, i.e. by size, functional ability, qualitative output and cost.

v) A number of colour pens can be fitted which can each be operated by pre-set commands.

Pen plotter costs vary (for large plotters) from $5 000 to $12 000.

Figure 6.17 Flatbed Plotter Showing Pen Holder Variations (from Kadmon, 1988)



E) *Electrostatic Plotters.* These operate in a similar way to photocopiers. An array of nibs (electrodes) selectively deposit charges on chemically treated paper in the form of an image. Toner is then made to adhere to the charged areas. Once the data has been processed into a suitable format they work very quickly, producing up to 60 x A0 drawings per hour in monochrome, or 10 in colour. They produce medium to high quality hard-copy on high quality paper in up to four colour shades. The cost of these plotters decreased by 50% between 1986 and 1989 - though they are still about $20 000.

F) *Direct Thermal Plotters.* These can deliver monochrome A0 plots at a speed of 20 per hour. They use a paper heating process which affects the chemical properties of the special heat-sensitive paper, causing it to turn black where desired. The paper is expensive and, being light sensitive, it is unsuited to archiving. By 1991 film media will be available to give long life impressions. A high resolution 400 dpi model costs about $30 000.

G) *Screen Copy Devices.* These devices are connected to the port of a graphics workstation and produce hard-copy of the graphic (or text) image appearing on the monitor. They can produce proofs for editing or final plots for use in documents. There are various different devices working on impact, electrostatic, thermal transfer and ink jet printing technologies. Trends in these devices include higher resolution, increased use of colour and falling costs. Present costs range from $2 500 to $5 000.

Other output devices include various cameras, optical film writers outputting to colour micro-film and colour slides and light spot projectors.

6.4.6 Data Base Management Systems

Again space prohibits a detailed discussion of data base management systems (DBMS), but there are many basic texts available, e.g. Laurie (1983), Walsh (1985), Date (1986), Austin (1989) and Maguire (1989) and Dale (1990). We must start off by defining a data base. This is a large organized collection of data which should be independent of any particular application and therefore usable in any desired way. It represents the top of a structured hierarchy which consists of fields, records, files and data bases. To exemplify this - if a data base were to be established on river water quality within a country or region, it would be necessary to take a sequence of steps:

i) At each river sampling point measurements of different water quality parameters would be made.

ii) Each water qualitative parameter measured (observed) would constitute a field.

iii) A collection of all the qualitative measurements (fields) taken at one location would be a record.

iv) A collection of all records made along one river, or stretch, would make up a file.

v) A collection of all files for the country or region would make up a data base.

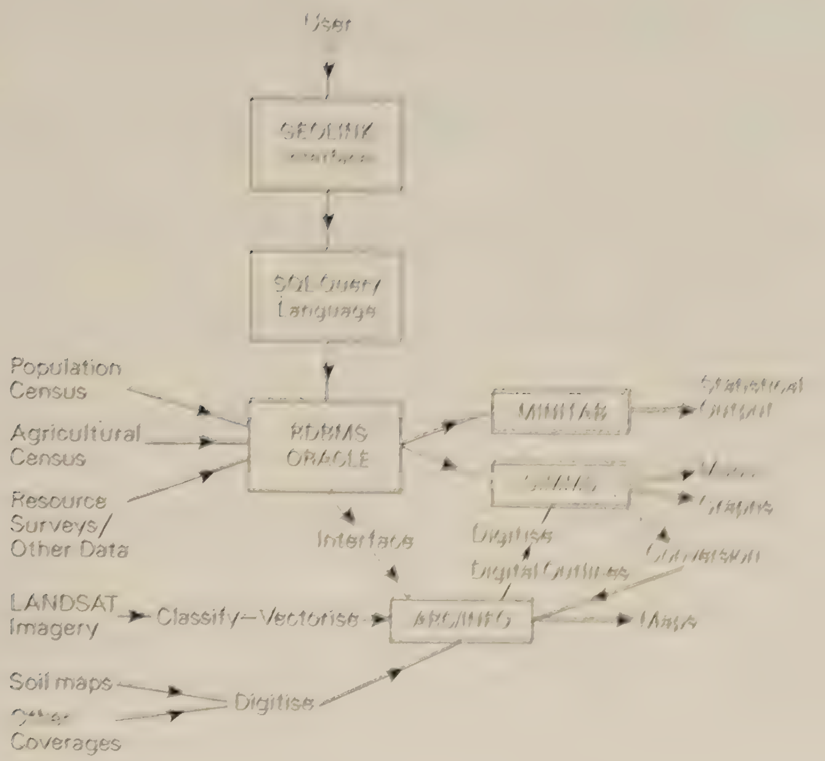
Individual files within the data base may be organized in various ways, and the whole data base can be structured in several ways, e.g. commonly using hierarchical, network or relational models.

A DBMS is a computer programme for creating, maintaining and accessing a data base. They can mostly handle numeric and alphanumeric data and they can provide the essential linkage between the user, graphic and other data, plus a range of external computer packages for mapping and statistical analyses. Relational DBMS are now acknowledged as offering the most flexible access to data since they allow independent sources of attribute information to be "joined" in order to create new relationships. Robinson *et al* (1989) show how a RDBMS fits centrally into a specifically designed GIS, made up by interfacing a number of independent software packages (Figure 6.18).

The reasons for having a DBMS are that all large collections of data, which are available to more than one user, require rules to maintain and manage them so that they remain usable. Since the volume of data is increasing exponentially, the importance of management is being increasingly magnified. It is also most important that large data bases have efficient storage structures, both to minimize storage space and so that they can be efficiently searched or analyzed, and users need to give careful consideration to the exact requirements of the data structure and contents before establishing files or data bases. Maguire (1989) points out that in reality a DBMS isolates end users from the complexities of computer systems, providing them with an easy to use management and analysis system, the functioning of which they will be completely ignorant of.!

The most important facility of a DBMS is their query language. This should provide for easy access to the data and allow for grouping, ordering, selecting and basic statistical procedures as part of the query,i.e. the query language offers opportunities for examination of specific relationships within the data and flexibility in manipulating data into the correct form for passing on to other packages within the GIS (Figure 6.18). DBMS should also allow security or protection to be maintained, if necessary by restricting access to parts of the data base. This may be done by making certain data unintelligible, perhaps by storing them in coded formats, by limiting levels of disaggregation or requiring that certain passwords are known in order to gain access to data or to the GIS.

Figure 6.18 The Integration of External Software into a GIS via a RDBMS


User
GEOLINK
interface
SQL Query
Language
Population
Census
Agricultural
Census
Resource
Surveys/
Other Data
RDBMS
ORACLE
MINITAB
Statistical
Output
GIMMS
Maps
Graphs
Interface
Digitise
Digital Outlines
Conversion
LANDSAT
Imagery
Classify—Vectorise
ARC/INFO
Maps
Soil maps
Other
Coverages
Digitise

ORACLE: This RDBMS is used as the core of the system. ORACLE is one of the most widely used RDBMS currently available. It provides a full range of database facilities, making use of the SQL query language, an acknowledged worldwide standard.

GIMMS: This is graphics software developed within Edinburgh University. It offers high quality graphics for the mapping of distributions and located point symbols.

MINITAB: A statistical package used to perform statistical operations such as correlation and regression and statistical hypothesis testing. Results of such operations can be relayed to ORACLE for storage or to GIMMS for mapping.

ARC/INFO: This is a commercially available GIS developed by ESRI Inc. of Redlands, California. The system consists of a graphics package (ARC) and a relational type file handling system (INFO). In the GIS of Belizean agriculture INFO has been used purely as a store for data passed from ORACLE. The software necessary to make this connection has been purpose designed in Edinburgh.

GEOLINK: Interfacing software, providing user friendly menus and enabling linkages to be made between the other software packages.

6.5 GIS Software

In this section we will briefly consider three aspects of GIS software. After an introduction, we discuss the varied characteristics of the GIS software milieu. Unlike other sub-sections of GIS, any discussion of software is difficult to structure in a logical way. It seems important to show why this is so. Our intention will not be to confuse the reader - it is to make him or her aware of the extraordinary complexity of this aspect of GIS! We conclude with a review of some varied GIS software packages. Further sources of information on GIS software will be given in Section 6.8.

6.5.1 An introduction to GIS software

Any computer software are basically coded programs which are input to the computer to make it function. Programs may be written in various computer languages and may be written to several kinds of input media such as CCTs and disks. Software programs can be generally classified as:

i) Operating systems (systems software) which control the individual tasks of particular computers, e.g. MS-DOS or UNIX.

ii) Assembler, compiler and interpreter programs which are used to translate computer languages into machine codes.

iii) Individually written programs (applications software) which anyone, having the necessary skills, can write.

iv) Pre-written commercial applications programs - which allow any of a huge range of tasks or games to be performed.

v) Large multi-purpose programs - called packages, which usually perform a range of related tasks.

True GIS software would come under heading (v), though for the functioning of GIS, operating systems software is essential, and software classified under headings (ii), (iii) and (iv) might be used, especially the latter. User interface with software programs may be by typing commands, by selecting from "menus" which increasingly are of the "pull-down" or "pop-up" type.

GIS software is mostly designed to carry out some or all of the functions listed in Table 6.1. The first specifically GIS programs and packages were produced in the mid-1970s in North America, by a variety of private and public companies or departments. Their evolution and categorization has been complex but there are now over 50 genuine GIS software packages on the world market (Montgomery, 1989). This market is certain to grow rapidly as prices drop and as the trend towards producing GIS software for the microcomputer continues, i.e. over half of all GIS software now runs on microcomputers, and prices for some quite sophisticated packages are below $100. Table 6.3, compiled recently by Dennison Parker (1989), shows details on most available GIS software. Maguire (1989) argues that "Such is the importance of software at the present time that many computers are bought and sold, not on the specifications of hardware, but on the ability to run popular software." (p.208).

6.5.2 The Varied Characteristics of GIS Software

In some ways it is impractical even to consider GIS software and hardware separately since in many cases they are integrally linked. Thus much software is specifically written for hardware systems and many GIS distributors are offering complete "turn-key" packages, having not only integrated hardware and software, but also complete user support facilities. Having said this, we can look at some ways in which GIS software is so variable.

6.5.2.1 Software evolution

Much of what might now be called fully functional GIS software has either evolved from other related fields or it has evolved from the needs to perform individual GIS functions. The major evolutionary force was perhaps that of Computer Aided Drawing (CAD), though more recently the field of computer graphics has spawned much software. The RS industry has given incentives to image processing software, much of which is now integrated into full GIS. Some of the manipulative and statistical software components have borrowed heavily from existing statistical programs and externally-derived DBMS programs are increasingly being integrated to GIS. Most recently there is an emphasis on devising software based on the needs of geographical (spatial) analysis. Software tends to retain its raster or vector data storage basis, depending on the evolutionary line it followed.

Table 6.3 Survey of Most GIS Software Available in 1989

ystem Name	Computing Environment	System Type	First Installed	Number of Users	Pricing	Data Structure(s)	DMBS Interfaces
GIS	PCs/DOS	GIS	1986	12	$15,000+	Vector, raster	na
RC/INFO	DEC, PRIME, DG, IBM, etc.	GIS	1981	nr	nr	Vector	Info, Oracle, Ingres
ries	DEC VAX/VMS	IP	1978	2,004	$65,000	Raster	na
TLAS* Graphics	PCs/DOS	DM	1984	1000's	$450-1,200	Vector	DIF, Dbase, Lotus, etc.
xis Mapping Info.	PCs/DOS, Sun Apollo, VAX IBM/UNIX	GIS	1978	25+	£7500-15000	Vector, Raster	na
RIES-GIS	PCs/DOS	GIS	1978	60	$1,500	Raster	Dbase III
eltamap	HP9000, SUN, APOLLO, SGI/UNIX	GIS	1986	100+	$8000-80,000	Vector, raster, TIN	Oracle, Ingres, Informix
arth One	PCs/DOS	GIS	1986	40	$12,000-28,000	Vector & raster	na
PPL7	PCs, PS-2/DOS	GIS	1987	335	$500-1,000	Raster	Rbase, Dbase III
RDAS	PCs/DOS; SUN/UNIX; VAX/VMS	GIS, IP	1979	900+	$2,000	Raster	Infor
ilevision IV	Macintosh	FM, DM	1984	40,000	$495	Raster	na
MS/AC	PCs/DOS; SUN/UNIX; Macintosh	GIS, FM	1987	500	$2,500-7,500	Vector	Dbase, etc.
as, Electric, Water & unicipal FM	IBM 370/MVS, VM	GIS, AM, FM	1984-89	22	nr	Vector	IMS, DB-2
Geo Sight	PCs/DOS	GIS, AM	1987	65+	$4,450	Vector, quadtree	Dbase
Geo-Graphics	PCs/DOS	FM	1985	nr	$2,400	Vector	na
GeoSpread-Sheet	PCs/DOS	GIS	1989	18	$595-2,490	Vector	na
Geo/SQL, MumMap	PCs/DOS; Sun/UNIX	GIS	1987	240	$9,500+	Vector	Rbase, Oracle, Ingres
GeoVision	VAX/VMS, ULTRIX; SUN, IBM-RT/AIX	GIS, FM	1976	47	nr	Raster, vector quadtree	Oracle
Geovision "GeoPro"	PCs/DOS Macintosh	AM	1988	2	$1,995-4,995	Vector	SQL & DBF supported
Geovision WOW	PCs/DOS	GIS	1985	1,200+	$595	Vector	nr
GFIS	IBM S/370 architecture systems	GIS	1977	180+	var.	Vector	IMS/DLI, SQL/DB2
Gimms	Mainframes, Minis (inclu. UNIX); PCs/DOS, Macintosh	DM,GIS	1970	300	$1500-$3000	Vector, raster	Oracle, SAS, SPSS
GISIN	PCs, PS-2/DOS	FM	1986	5	nr	Vector	Condor
GDS	VAX/VMS, DEC station/Ultrix	GIS, AM	1980	800+	$10,000+	Object (vector)	Oracle, etc.
GRASS	Sun, MASSCOMP, etc./UNIX	GIS	1985	500-100	$1,000	Vector, raster	nr
IDRISI	PCs/DOS	GIS	1987	700	$50-300	Raster	Lotus, Quattro, etc.
IGDS/DMRS	DEC VAX/VMS	CAD-CAE FM-GIS	1973	1371	$7,500-110,000	Vector, raster	Informix
IMAGE	PCs/DOS	GIS, IP	1989	100+	$995+	Vector	Lotus, Dbase, etc.
Infocam	VAX/VMS	GIS	nr	23	$40,000-65,000	Raster, quadtree	Oracle
Informap	VAX/VMS	GIS	1975	nr	nr	Vector	SQL-based
Land Trak	PCs/DOS	GIS	1983	230	$3,000-$20,000	Vector	na
Laser-Scan	DEC VAX/VMS	GIS	1985	150	£10,000-100,000	Vector, raster	RDB
Mac GIS (Cornell U.)	Macintosh	GIS, AM, FM	1988	nr	150	Vector, raster	na
MacAtlas, PCAtlas	Macintosh, PCs/DOS	GIS	1985	5000+	$79-199	Vector, raster	na
MacGIS (U. Oregon)	Macintosh	GIS	1987	30	$100-300	Raster	Hypercard, etc.

(cont.d)

Table 6.3 Survey of Most GIS Software Available in 1989 (continued)

System Name	Computing Environment	System Type	First Installed	Number of Users	Pricing	Data Structure(s)	DMBS Interfaces
Manatron GIS	Unisys/DOS, UNIX	GIS	1983	60+	nr	Vector, raster	Oracle, Fasport, Adept, Request, etc.
Map Grafix	Macintosh	GIS, AM	1987	nr	$8,500	Vector	4th Dimension, Oracle, Double Helix, Omnis, etc.
Map II	Macintosh	GIS	1989	nr	<$100	Raster	no
MapInfo	PCs/DOS	GIS	1986	nr	$750	Vector	Dbase
MatchMaker/GDT	PCs/DOS	DM	1987	10	$5,995-9,995	Vector	na
Micropips	PCs, PS-2/DOS	AM	1981	250	$745-1,490	Raster	
MicroStation GIS	Intergraph/UNIX	GIS	1989	11	$8,300	Vector, raster	Oracle, Ingres, Informix
MIPS	PCs/DOS	GIS	1987	nr	$2-5,000	Vector, raster	Dbase
MOSS	DG, Prime	GIS, IP	1977	>100	(public)	Vector, raster	DG/SQL, Oracle
Nucor GIS	PCs/DOS	GIS	1988	10	$500-4,500	Vector, raster	ZIM
Pamap GIS	Var./VMS, DOS, UNIX, ACS, CS/2	GIS	1983	200	$7,500-$60,000	Vector, raster	RDB, Oracle, Dbase
Panacea	PCs/DOS	GIS	1986	500	$500-2,000	Raster	na
PC ARC/INFO	PCs, PS-2/DOS	GIS	1987	nr	nr	Vector	Info
PMAP	PCs/DOS	GIS	1987	180	$895-1,600	Raster	Dbase
SICAD	Siemens/UNIX	GIS	1978	250	£20,000+	Raster, vector, quadtree	DB2, Informix, etc.
SPANS	PCs/DOS, OS2	GIS	1985	400	$8,000+	Raster, vector, quadtree	nr
StrataGIS	Tektronix/UNIX; IBM PCs/DOS	GIS	1988	20	$7-25,000	Vector	Unify
STRINGS	PCs/DOS	GIS/FM	1979	150	$3,500-5,000	Vector	Ingres, Sybase Britton Lee
System 600	VAX/VMS,Sun/UNIX	GIS	1984	200	$10,000-50,000	Vector, raster	Ingres
System 9	SUN/UNIX	GIS/IP	1987	25	$40,000	Vector	Empress
Territory Mgt. Sys.	PCs/DOS	GIS	1988	25	$2,950-3,950	Vector, quadtree	Dbase
Tigertools	PCs/DOS	GIS	1989	2	nr	Vector	nr
TIGRIS	Intergraph/UNIX workstations	GIS	1988	16	$10,000	Vector, raster	na
Topologic	PCs/DOS; OS-2; VAX/VMS	GIS	1987	18	$2-7,000	Raster, vector, quadtree	Dbase, RDB
UltiMap	Apollo, AEGIS Operating System	GIS, AM	1974	40	$19,000-50,000	Vector, raster	Oracle, Informix, Ingress, IMS, etc.
USEMAP	PCs/DOS	GIS, AM, FM, CADD	1973	3	$1,500-5,000	Vector, raster	Dbase III
VANGO	VAX/VMS	GIS	1981	96	$12,000-17,000	Vector	UserBase
Zone Ranger/GDT	PCs/DOS	AM	1987	3	$5,995-9,995	Vector	na

6.5.2.2 Software ownership

In the U.S. especially, from where most software originates, there are two main classes of GIS software in terms of legal ownership, i.e. that in the public domain (government funded and researched) and private (owned by the author or their employer), plus some which falls in the grey area where ownership is uncertain. This causes some problems since public domain software can be sold for prices which cover little more than distribution costs, and since they are so cheap they are often copied or "dubiously acquired" for integration into expensive commercial packages. Most public domain packages provide little or no support facilities, though some, such as GRASS (developed by the U.S. Army Corps of Engineers), is well supported.

6.5.2.3 Linkages between companies or organizations

Because much of the software has its roots in various fields, i.e. in government departments, in universities or in large and small private companies, each of whom may be producing a different software commodity, a number of complex linkages are occurring as the industry is achieving both an optimum production equilibrium (in terms of systems variety), and economies of scale. Alternatively, some universities or government departments are marketing their own products or they are setting up private companies to do this.

6.5.2.4 Pricing policies

Software packages are extremely difficult to price and prices show huge differentials. This results from:

i) The previously mentioned public v. private ownership problem.
ii) The fact that different software performs huge ranges of possible functions.
iii) Software is produced for a large variety of computer types.
iv) Software companies determine their prices in different ways, though this is usually determined by dividing the investment made by the perceived market.
v) There are frequently different prices for the same product if sold to students, or for research or sold to private companies.

6.5.2.5 Software functional range

It will be clear from the above that software ranges from single or modular programs, which are capable of being linked to a GIS to perform specific functions, to large integrated packages which may perform all GIS functions. Some packages are specifically designed for mainframes or minicomputers, others for microcomputers, though increasingly the larger GIS companies are designing their programs to suit any size of computer. Many packages are "customized" to suit specific end-user requirements. Because of this functional range, no two programs or packages will be the same, and so it is impossible to compare one with another or to instigate any meaningful software classification system.

6.5.2.6 Other variations in GIS software

These may include:

i) "User-friendliness" - is the command language or menu system readily comprehensible?
ii) The ways in which graphics are integrated with attribute features.
iii) The structure of the DBMSs.
iv) The topological structure used.
v) The quality, quantity and diversity of product promotion.
vi) The ability of a software package to service a range of hardware devices, including workstations.

Table 6.4 The Range of Functions Available on Version 2.0 of IDRISI (from Eastman, 1989)

A. CORE MODULES

1. System Operation Modules.

ENVIRON	Changes the prevailing IDRISI operating environment.
LIST	Lists the names and stored titles of data files.
DESCRIBE	Describes the contents of a data file

2. Data Entry Modules

INITIAL	Initializes a new image with a constant value
UPDATE	Keyboard entry / update of image data
DIGITIZE	A Pascal source code digitizing shell that may be modified to work with any digitizing equipment
POINTRAS	Point-to-Raster conversion. (for conversion of digitizer output)
LINERAS	Line-to-Raster conversion. (for conversion of digitizer output)
POLYRAS	Polygon-to-raster conversion (for conversion of digitizer output)
INTERPOL	Interpolates a surface from point data using either a weighted-distance or potential surface mode.

3. Data Storage Modules

CONVERT	Converts data files from ASCII to binary or vice versa and integer to real or vice versa.
PACK	Converts integer data to run-length encoded or byte formats.
UNPACK	Converts run-length or byte data to sequential integer format.

4. Data Management Modules

DOCUMENT	Revises the documentation file of an existing image or vector file (or creates a new one for a foreign file)
CONCAT	Concatenates two images to produce a new larger image.
TRANSPOS	Image transposition by row or column reversal or by rotation.
WINDOW	Extracts a rectangular subimage.
QUERY	Extracts pixels designated by an independent mask into a sequential file for subsequent statistical analysis.
EXPAND	Enlarges an image by pixel duplication
CONTRACT	Reduces an image by pixel aggregation or thinning.

5. Data Retrieval and Display Modules

COLOR	Produces color output of images on selected display hardware. IBM CGA = 160 X 100 X 16 colors or 320 X 200 X 4 colors / IBM EGA or VGA = 640 X 350 X 16 colors (chosen from 64) / DEC Rainbow = 384 X 240 X 16 colors (chosen from 4096) or 384 X 240 X 4 or 16 shades monochrome / Hercules = 240 X 174 X 7 shades or 180 X 116 X 13 shades. COLOR incorporates autoscaling to allow the examination of any image.
IMAGE	Produces a grey-scale image (up to 32 levels) using dither patterns on dot-matrix printers. Also supports HP Paintjet with 16 colors chosen from a palette of 330.
ORTHO	Displays three dimensional perspective models of surface images (CGA, EGA, VGA, MCGA and Hercules graphics cards).
DISPLAY	A "universal" display routine using ASCII characters or downloadable fonts.
VIEW	Allows direct examination of any portion of an image. Output precision is user-specified.
HISTO	Produces histograms of image file values. In addition to the graphic output, numeric output includes proportional and cumulative frequencies along with simple statistics.
STRETCH	Produces a linear contrast stretch in preparation for image display using the IMAGE or COLOR modules.

6. General Analytical Modules

OVERLAY	Undertakes pixel-wise addition, subtraction, multiplication, division, and exponentiation of paired images. Maximum, minimum, "normalized ratio" (eg. vegetation index), and "cover" are also supported. On binary images, logical AND and OR operations are supported by means of the multiply and cover operations. Other Boolean operations such as XDR, EQV, NOT and IMP are supported through various binary image overlay combinations.
SCALAR	Adds, subtracts, multiplies, divides, and exponentiates pixels by a constant value.
RECLASS	Reclassifies pixels by equal intervals or user-defined schemes.
FILTER	Convolves (strictly correlates) an image with a digital filter. Mean, median, mode, edge-enhancement, low-pass and user-defined filter kernels are accommodated.

B. GIS RING MODULES

SURFACE	Produces slope gradient and aspect images from a digital elevation model
AREA	Creates a new image by giving each output pixel the value of the area of the class to which the input pixel belonged. Also produces summary tables in any of a wide range of units.
PERIM	Creates a new image by giving each output pixel the value of the perimeter of the class to which it belongs.
GROUP	Classifies pixels according to contiguous groups.
DISTANCE	Calculates the true Euclidian distance (proximity) of each pixel to the nearest of a set of target pixels.
COST	Generates a distance/proximity surface where distance is measured as the least cost distance in moving over a friction surface.
PATHWAY	Finds the shortest path between one or more specified points and one or more possible destinations specified as the lowest points on a cost surface.
VIEWSHED	Creates an image of all points visible from one or more viewpoints over a given surface.
WATRSHED	Creates an image of the watersheds of one or more features.
HNTRLAND	Determines the supply areas dominated by (i.e., the hinterlands of) point demand centers.
AUTOCORR	Computes Moran's "I" first lag image autocorrelation statistic (used with CONTRACT to calculate other lag).
QUADRAT	Performs Variance/Mean Ratio analyses on quadrat data.

C. PERIPHERAL MODULES

IDRTOMAP	Exports IDRISI images to the Map Analysis Package or pMAP systems.
MAPTOIDR	Imports mainframe or micro Map Analysis Package data into IDRISI format (pMAP separately accommodated).
RADIANCE	Converts LANDSAT raw Dn values to calibrated radiances using lookup tables.
DLG	Scans and extracts features from USGS DLG files into IDRISI format (provided with complete attribute dictionaries)

6.5.3 The Capabilities of Some Typical GIS Packages

For this section we have quite deliberately selected a small number of GIS software packages with the object of illustrating some of the tremendous range obtainable.

6.5.3.1 IDRISI

This is an extremely low-priced, raster-based GIS, which is able to provide the range of functions shown in Table 6.4. It was developed at Clark University in the U.S. and was specifically created for microcomputers. It is designed to be an inexpensive research and teaching tool that can become the focus for a collective program of system development and exchange. By using independent modules linked by a simple data structure, the system allows users to develop their own modules in any computer language. Users may also exchange new modules, data sets and experiences through an IDRISI electronic bulletin board.

The IDRISI system currently operates on all Intel 808x microcomputer systems running PC-DOS or MS-DOS 2.11 (or greater), using 5.25" or 3.5" disks. System requirements are few. Minimally, it requires 128 kilobytes of internal memory and two floppy disk drives, though optimally the system should have a hard disk, a colour graphics card and a dot matrix printer. With a typical 640K memory configuration, the system can theoretically process images as large as 10 000 columns by 32,767 rows. Figure 6.19 illustrates output capability using the "Image" module, in this case some Landsat TM data. Up to 32 half-tone grey levels can be printed. The latest version is 3.2 released in late 1990, at three price bands of <$150. Further details can be obtained from Eastman (1989).

6.5.3.2 MundoCart/CD

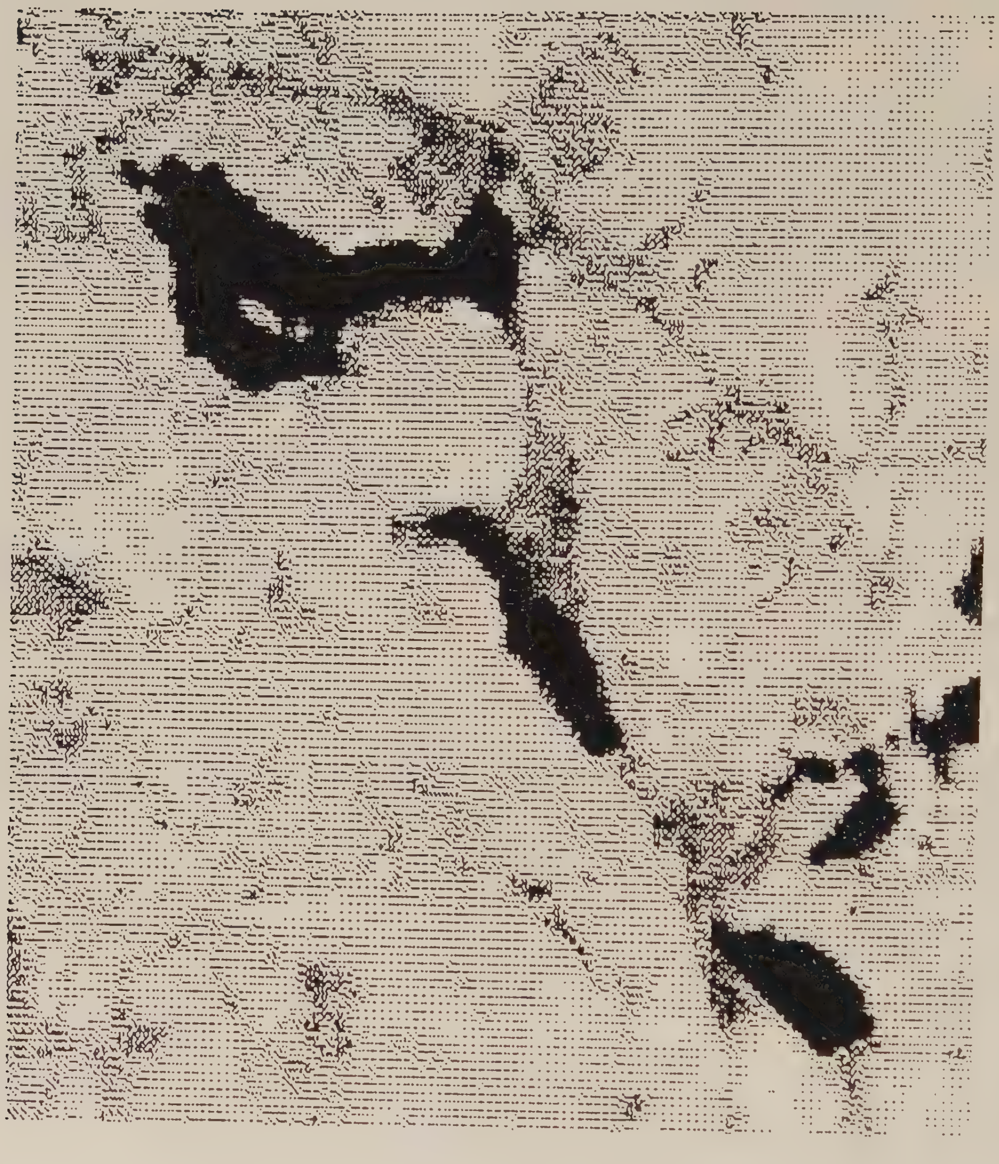
This is an example of a single function data base designed for use independently or for integration with a GIS. It is of particular value to aquaculture and inland fisheries, as is demonstrated in Table 6.5 which shows MundoCart's feature classifications. This software produces seamless high-quality maps of any part of the world in a range of scales from 1:250 000 to 1:150 000 000. Users can add their own data to base maps produced by the package or extract cartographic data from it for use with other data bases and with GIS, i.e. it eliminates the need to draw or digitize map outlines. The MundoCart map data base is contained on one CD-ROM - associated software enables the information to be retrieved and manipulated. It is designed for PC use and is distributed by Chadwyck-Healey Ltd.

MundCart contains 20 million mapping points defining the earth's surface, including 500,000 separate features and 60 000 names of places and features. A choice of 24 different projections and 26 ellipsoids is available, and in addition to the complete data base, MundoCart can be purchased in eight regional subsets or combinations of subsets. The complete data base costs about $15 000, though a 50% educational discount is available. Regional subsets are priced at about $3 500 for the first and $3 000 for additional ones.

6.5.3.3 GIMMS

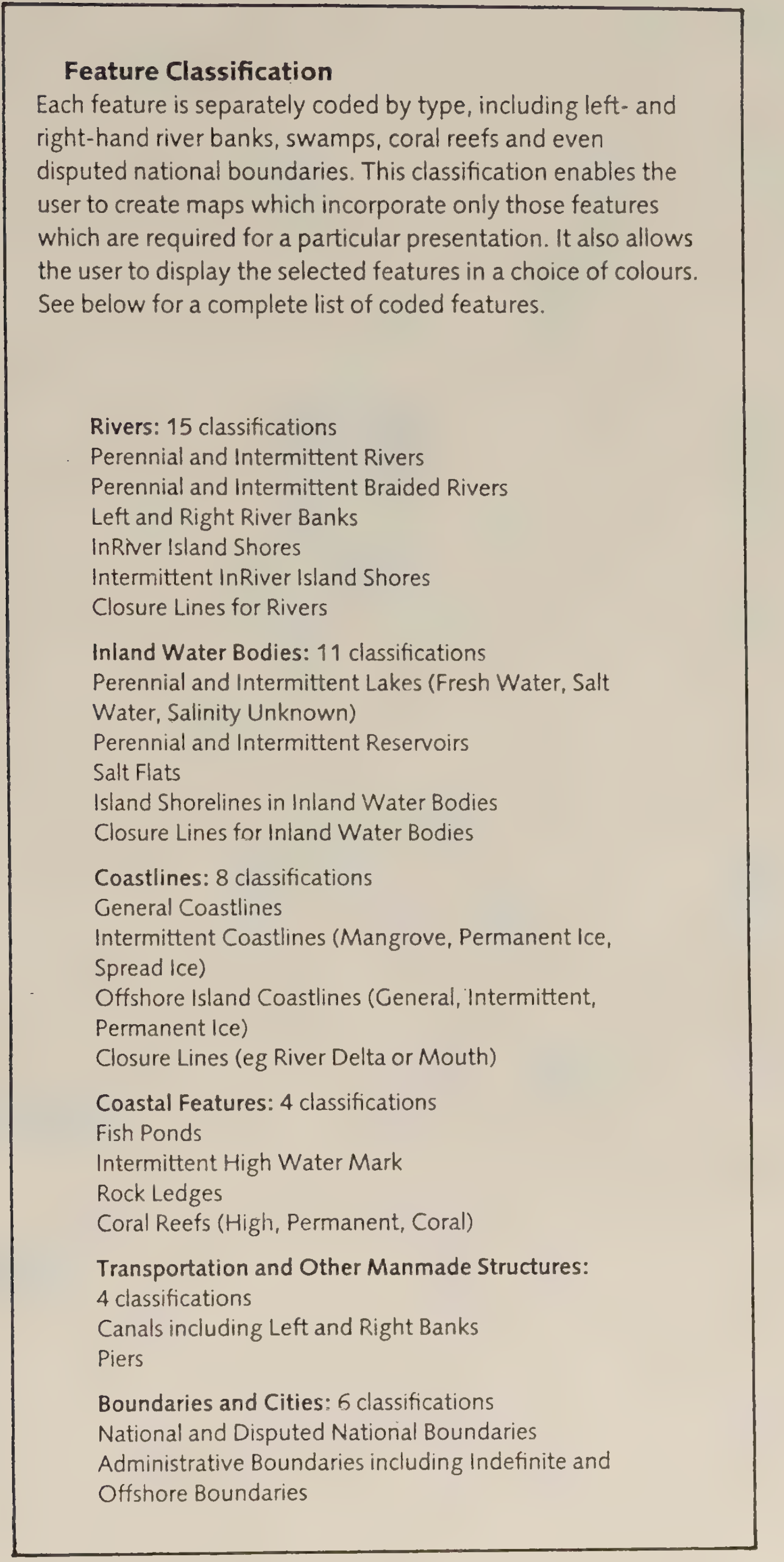
Information on this software is obtained mostly from Maguire (1989) though complete details can be had from Carruthers (1985). GIMMS is a high level, command-oriented, computer cartography system that can be used in both batch and interactive modes. It was initiated in 1970 at the University of Edinburgh, and has subsequently been updated on several occasions.It is currently one of the most widely used cartography packages. It is available for a wide range of mainframe and minicomputers, and is about to be released for microcomputers. GIMMS may be used to create two basic types of cartographic image, i.e. statistical graphics such as line graphs, pie charts and histograms, and maps of points, lines, areas and surfaces. GIMMS is organized as a series of modules each of which covers one aspect of the image creation process. Figure 6.20 illustrates an example of GIMMS output.

Figure 6.19 A Portion of a Print Out From the IMAGE Module of IDRISI



The microcomputer version of the full GIMMS software package will be available in 1990 for the IBM PC/PS range (or compatibles) using MS-DOS or OS/2. It will require an 80286 or 80386 processor and at least 3 Mbytes of memory plus a hard disk with at least 5 Mbytes of available space. Peripherals supported include all screens supported by GSS/IBM plus virtually all major plotters. The price of the GIMMS-PC software will be about $1 700 with a 50% discount for academic users.

Table 6.5 Classification of Features Available on MundoCart/CD



Feature Classification

Each feature is separately coded by type, including left- and right-hand river banks, swamps, coral reefs and even disputed national boundaries. This classification enables the user to create maps which incorporate only those features which are required for a particular presentation. It also allows the user to display the selected features in a choice of colours. See below for a complete list of coded features.

Rivers: 15 classifications
Perennial and Intermittent Rivers
Perennial and Intermittent Braided Rivers
Left and Right River Banks
InRiver Island Shores
Intermittent InRiver Island Shores
Closure Lines for Rivers

Inland Water Bodies: 11 classifications
Perennial and Intermittent Lakes (Fresh Water, Salt Water, Salinity Unknown)
Perennial and Intermittent Reservoirs
Salt Flats
Island Shorelines in Inland Water Bodies
Closure Lines for Inland Water Bodies

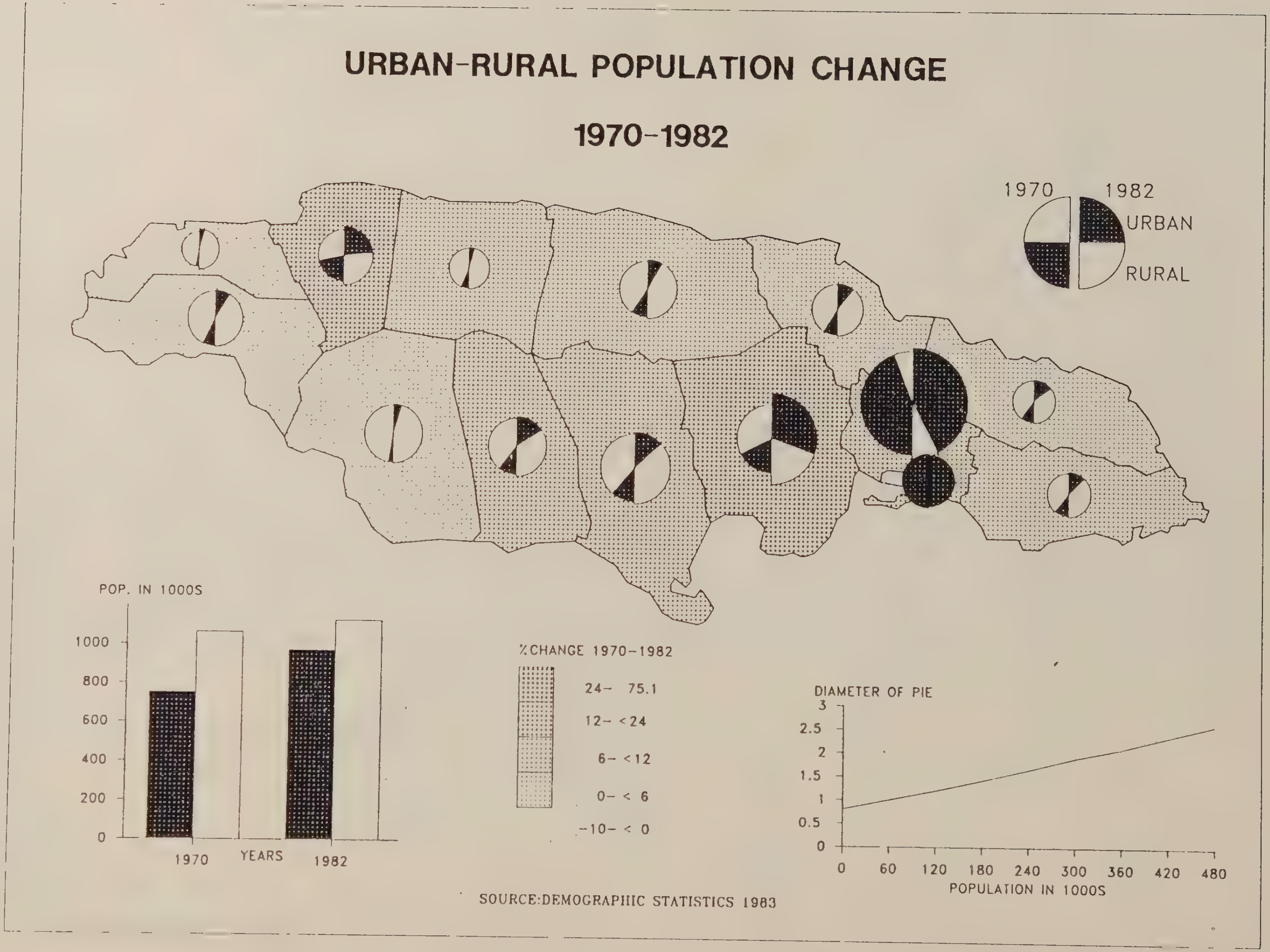
Coastlines: 8 classifications
General Coastlines
Intermittent Coastlines (Mangrove, Permanent Ice, Spread Ice)
Offshore Island Coastlines (General, Intermittent, Permanent Ice)
Closure Lines (eg River Delta or Mouth)

Coastal Features: 4 classifications
Fish Ponds
Intermittent High Water Mark
Rock Ledges
Coral Reefs (High, Permanent, Coral)

Transportation and Other Manmade Structures: 4 classifications
Canals including Left and Right Banks
Piers

Boundaries and Cities: 6 classifications
National and Disputed National Boundaries
Administrative Boundaries including Indefinite and Offshore Boundaries

Figure 6.20 An Example of GIMMS Output Showing Some Population Statistics for Jamaica


URBAN-RURAL POPULATION CHANGE
1970-1982
1970
1982
URBAN
RURAL
POP. IN 1000S
1000
800
600
400
200
0
1970
YEARS
1982
%CHANGE 1970-1982
24- 75.1
12- <24
6- <12
0- < 6
-10- < 0
DIAMETER OF PIE
3
2.5
2
1.5
1
0.5
0
0
60
120
180
240
300
360
420
480
POPULATION IN 1000S

SOURCE:DEMOGRAPHIC STATISTICS 1983

6.5.3.4 ARC/INFO

This GIS is supplied by Environmental Systems Research Institute (ESRI) from California, and the company claims this product to be the world leader in GIS in sales/installations. ARC/INFO is designed to run on a variety of 32-bit mini and mainframe computers plus IBM PC/AT compatible microcomputers and 32-bit workstations. The system performs a complete range of GIS functions (Table 6.6), and emphasis is placed on an efficient relational and topological data model for entry, analysis and management plus clear user interface incorporating "pull-down" and "pop-up" windows. ARC/INFO uses an integrated Henco INFO RDBMS, but it also allows the user to integrate other RDBMSs such as ORACLE, INGRESS and dBASE III. This integration introduces increased functionality including transactional data management, multi-user access, data dictionaries and the use of screen editors for attribute entry and updates.

ARC/INFO is composed of two tightly integrated software components: ARC, used to manage cartographic data, and INFO, used for managing tabular data describing cartographic attributes. The entire ARC/INFO system operates in five different computing environments: Prime, DEC VAX, Data General, IBM (VM/CMS) and Sun plus the IBM PC/ATs. The software supports numerous drivers for graphics screens and it contains the Tektronix IGL Library which allows users to write their own device drivers for virtually any device. ARC/INFO supports a variety of normal plotters plus high resolution, colour electrostatic plotters. The prices for software on mini and mainframe computers range from $20 000 to $90 000, depending on the size of the machine, number of packages and location. The PC version is sold as a series of individual software modules, each costing $1 000 - $2 500. PC ARC/INFO can be acquired as a complete "turn key" system, including hardware, for under $25 000.

6.6 The Benefits and Problems of Using GIS

Since GISs are so complex, and since the technology and infrastructure behind GIS has emerged so recently and rapidly, then there are certain to be problems which the potential user must face. On the other hand, GIS would not have expanded so quickly unless there were a great number of benefits. We shall consider benefits and problems from the actual and potential users viewpoint - those within the industry might visualize a completely different set of benefits and problems. Since a list of these might be vast we have selected arguably the 10 major ones in each category. In looking particularly at the problems of using GIS, we would bring attention to one paramount concern which has been repeatedly emphasized and is summed up in Dept. of Environment (1987) - "The success or failure of a GIS effort has rarely depended on technical failures, and almost always on institutional or managerial ones." (p.154). It seems to many that a tremendous degree of effort and speed has been put into GIS technological and theoretical developments - maybe a pause to catch up and reflect is now overdue! Useful further reading on benefits and problems can be had from Burrough (1986), Dickinson (1989), Goodchild and Gopal (1989) and Tomlinson (1989).

Table 6.6 GIS Functions Supported by ARC/INFO Relating to Aquaculture and Inland Fisheries

GIS Functions	Fish and Wildlife	Water Resources	Agriculture/ Soils
Tabular Data			
Data entry	X	X	X
Update	X	X	X
File management	X	X	X
Manipulation (Arith/logical)	X	X	X
Statistical analysis	X	X	X
Query/browsing	X	X	X
Report generation	X	X	X
Cartographic Data			
Graphic digitizing	X	X	X
Survey traverse entry (COGO)			
Interactive graphic editing	X	X	X
Spatial templating	X	X	X
Map join/edge match	X	X	X
Polygon overlay with sliver removal	X		X
Vector/raster conversion	X		X
Polygon dissolve	X		X
Line-in-polygon/Point-in-polygon	X	X	
Transformations	X		X
Buffers/corridors	X		
Windowing	X	X	X
Co-ordinate filtering	X		X
Proximal analysis			
Linear distance calculation			
Area/perimeter calculation	X		X
Spatial aggregation/districting			X
Contiguity analysis	X		
Network analysis			
Spatial query		X	
Interactive graphics	X		
Graphic superimposition	X	X	X
Polygon mapping	X	X	
Point mapping	X	X	X
Line mapping	X	X	X
Feature symbolizing/shading	X	X	X
Annotation/text	X	X	X

6.6.1 The Benefits of GIS

1) GISs help the planner to make trade-off decisions in resource allocation, i.e. using an interactive VDU, varying assumptions and criteria can be instantly simulated and manipulated to generate different final scenarios, or to test varying hypotheses. This allows the planner a range of choices from which a decision can be made.

2) GISs allow for a range of data, perhaps from widely differing spatial sources, to be entered into an analysis scenario - much of it also coming from different fields of study. For example, in site selection for coastal aquaculture, field work data, RS imagery, secondary maps and tabular data from the fields of recreation, resource extraction, biological diversity, scenic valuation, existing land use, etc., could all be rapidly integrated into the decision-making process.

3) GISs are applications-oriented. They bring a spatial technology immediately to bear on real world problems. They can instantly show the crucial part that both location and spatial differentiation play in optimizing socio-economic well-being.

4) GISs have greatly expedited the speed of working across a whole range of functions. It has provided its user with rapid access to a huge volume of data ensuring that decisions or outcomes have an added degree of objectivity, this being accomplished in some situations in near real time.

5) Once digitized, any GIS data can be quickly and efficiently updated, meaning that more frequent revisions become possible.

6) Time series changes can be monitored rapidly, and statistical calculations of these can be quantified, allowing future projections to be estimated.

7) The cost-effectiveness is such that GIS allows a company to be competitive in various ways, e.g. in optimizing its location. It also allows public services to be more efficient and cost-effective.

8) GIS allows for the production of special purpose (perhaps 1-off) maps to be produced at low cost, and for the propagation of a large variety of maps, or other output data, which might not otherwise have been produced.

9) GIS technology enables a high quality of output to be reached and standardized by a large number of people who might have no cartographic or draughting skills.

10) For the research and academic user, GIS not only enhances the opportunity to describe, explain and predict spatial patterns and processes, but they also allow sophisticated and realistic models to be formulated and tested. Maguire (1989) suggests that GIS may stimulate the development of a new philosophy which integrates the work of human and physical geographers plus those in a number of related disciplines.

6.6.2 The Problems of GIS

1) Many of the benefits of GIS cannot be assigned a monetary value, e.g. intangible benefits such as "better decision-making", "better planning" or "better information". These benefits could well be greater than the actual increases which can be measured such as costs of producing maps or consultancy costs. The actual value of acquiring a GIS is very difficult to demonstrate.

2) The extremely slow process of digitizing existing maps data means that the user must incur a high cost for the digital conversion, i.e. up to 75% of total monies spent on GIS by

some users is in data capture or conversion. This means that much potentially valuable data will remain "locked up" for many years.

3) The poor quality of much existing hard-copy graphical or tabular source data which, when input to the GIS, causes error propagation. Some errors are caused by the "fuzziness" of the entity, e.g. "The Alps". How does data covering this vague region get precisely captured? Other errors occur as a result of using dated sources, poor digitizing, poor sampling, processing mistakes, conversions of data, classification mistakes, etc. Algorithms need incorporating which allow for estimated confidence limits of the output data, plus error-train analysis to assess the potential results of propagating errors.

4) Who will be responsible for updating digital data and deciding which institutional data will be regularly updated?

5) The means and the rights to gain access to information. At present they not only vary greatly from country to country, but the legal framework is often either extremely poorly determined or is unnecessarily restrictive. There are legitimate copyright problems in making all data available to the public, plus the problems of ownership of digital data, e.g. if a new set of data is produced from another owner's source material.

6) There is a critical shortage of trained people in GIS, i.e. in understanding the technology, in spatial analysis methods, in applications design, etc. There are too few training places and teachers, inadequate research and funding plus a lack of understanding that the problem even exists! This situation is likely to continue in many countries whilst governments show little interest in geographic data handling.

7) How to cope with the huge data influx which is exponentially occurring, e.g. by 1994 the EOS satellite alone will generate 10 million million bits of data per day, and a simple U.K. Ordnance Survey sheet occupies about 240 million bits. This data somehow needs storing, archiving, structuring and processing - better methods must be found. How do we evaluate if the data being acquired is really necessary?

8) There is no international format, or set of agreed standards for GIS data, which would enable data of known quality to be easily transferred among different users. Associated with this is the fact that much data is collected by groups who might not wish to exploit the spatial aspects of it, so they are not obliged to provide the data in a form which might facilitate spatial analysis.

9) Many systems still lack "user-friendly" interfaces which would make them more readily accessible to non-expert users. These people may understand what they wish to get from the GIS, but they do not wish (or have time) to absorb either vast instruction manuals or the intricacies of computer operation. In many cases this might have led to user resistance to the new technology.

10) The problem of getting access to data in the sense of actually finding what the user requires. Digital archives are hard to get information on (let alone from!), and browsing through data bases via on-line local or regional networks can be slow and ill-referenced. When data is found there can be scaling, processing or formatting problems.

6.7 Considerations in Choosing a GIS

GISs are successful when they comprehensively and consistently meet user requirements - world-wide a large number of GISs have failed to live up to expectations because in the planning stage user requirements were not identified and because users had not realized the correct potential of GIS. Users have also not made a detailed study of the data resources available or of the ability of the user or his organization to manage and maintain the system.

These considerations, plus the permutations of software and hardware available, can make the selection of GIS a complex procedure.

The impetus for wanting to implement a GIS has frequently come from an individual within an organization who has learned about it from a conference, workshop or the IT media, and who has advocated its adoption. This internal innovation has often been from the "bottom up" because many senior managers, unlike their junior counterparts, have failed to keep progress with IT. Tomlinson (in Dept. of Environment, 1987) notes that this "bottom up" approach has often led to unsuccessful GIS implementation because it has been piecemeal and lacking in wide company recognition. For successful implementation it is vital that the approach is systematic, looks at a very broad field and that a written report is produced which sets out a total implementation strategy, or perhaps a number of alternative plans, plus a very clear statement of the functional needs. The basic strategy report should set out to answer a number of basic questions, which we discuss here under various pertinent headings.

In compiling this chapter we will place the context of choosing a GIS on a variety of scales and in several situations. We need not look at the actual purchasing procedures and we will presume that a decision to implement computerization is agreed and that external facilities are available, e.g. office space, power supplies, etc. For further details on systems selection we recommend - de Man (1984), Burrough (1986), FICCDS (1988), Dangermond and Morehouse (1989), Guptill (1989), Montgomery (1989), Pearce (1989), Ventura (1990) and Pearce (1990).

6.7.1 Why Is a GIS Needed?

Since most companies or organizations will have progressed reasonably well without a GIS, it is very important to ask this! The answer lies both in tangible and intangible ways. From the aquaculture and viewpoint it has been made clear that there is an urgent need to secure and optimize suitable locations for fish production. From the inland fisheries viewpoint maintenance or enhancement of fish production from natural and man-made waters through ensuring good water quality and adequate quantities is of prime importance.

But as well as this it must be clear that GIS could be utilized by Fisheries departments in other tangible ways, e.g. in identifying market outlets, in identifying fish landing and processing sites, in allocating areas for exploitation for cooperative management of resources, in planning labour deployment and the supply of fishing gears, etc. Once GIS experimentation was completed and data bases were added to, then, if the experiences of other users is to be believed, other less tangible uses would be developed and deployed, e.g.:

i) In what way do fish catches vary across, and depth-wise, in an expanse of water, and why?
ii) Where do we have areas of protein deficiency?
iii) Is fish equally acceptable throughout our region, and if not, where and how much effort should we place on promotion?
iv) What are the correlations between fish acceptability (for consumption) and income?
v) With what social or physical features do present aquaculture facilities best correlate?
vi) Are aquaculture and fishery extension services properly allocated?
vii) Etc.

Needs are also related to efficiency. Careful consideration would need to be given as to the range of efficiencies, and implied cost savings, that GIS would bring, e.g. perhaps in resource deployment, in transport distribution patterns, in real time answers to quite complex spatial problems, in optimizing the temporal/spatial output of production by species, etc. If GIS is not adopted, it is possible that relative efficiencies would decline, leading to loss of competitiveness and a consequent loss in commercial market share, or in the case of government, to the poor allocation of resources.

We list a number of other pertinent questions regarding user needs:

i) Can the needs be better met elsewhere? That is, is the need for a one-time assessment, or for fairly continuous analyses?
ii) How urgent are our needs?
iii) How would existing employees accept GIS being introduced?
iv) What degree of "project awareness" should be raised in the organization?
v) How much say will the GIS users within the organization have in the acquisition decision?
vi) Are our needs for a GIS expanding or declining - or are they flexible?
vii) Do we need a GIS which provides simple drafting plans or highly sophisticated spatial analyses?
viii) How much do we know about GIS - as a company - as individuals?
ix) Where could we view a commercial or agency (rather than demonstration) GIS in action and speak to other users?

6.7.2 How Should a GIS Fit Into An Organization?

Many Fisheries departments, or other organizations contemplating securing a GIS, will have existing computing facilities, and there would certainly be a number of cost and personnel advantages to be had by sharing these facilities. But are these facilities available? - and in the right location? - and of the right "size"? - and have the desired peripherals? - etc.? Experience has shown that it is not easy to fit a GIS into existing facilities because GISs involve so many complex and systems-specific considerations, though GIS integration is certainly worthy of evaluation.

Perhaps the GIS should be a specific system which is accessible to a range of related disciplines, i.e. to personnel within a fisheries department, or to agriculture and fish production, or to food procurement generally. Or should it be even wider than this, e.g. a GIS which covers the entire resource planning or land use planning for a region or country? The answer to this will usually be determined by the structure and size of the organization contemplating GIS entry. We make the point here that much of the data to plan for agricultural development, or to assess environmental impacts are the very same data required to plan for fisheries and aquaculture. Therefore, there is a natural cohesion among the needs of various disciplines that could be satisfied by a single administration at a single location. However, it is usual that the optimum location for siting the GIS is closest to where most of the data bases are stored, or near to where data is available for capture, so this might determine the functional range of users who have access to one GIS.

It would be generally considered that the development of GIS is a highly centralized function, perhaps affecting the organization as a whole, and requiring resources which are beyond those of a "small Fisheries office". A central place, "head office" type of location is preferable for initial GIS instigation, though as the system develops and more local data accrues, then some of the work might be suitably carried out at GIS outposts. Certainly, individual Fisheries offices should not be allowed to develop their own preferred GISs, since the chances are that a diversity of incompatible systems would develop.

Some further pertinent questions are:

i) What is the current state of information technology within the organization?
ii) What spatially-referenced data is already held by the organization in computer readable form?
iii) Where is this data held, and is it able to be shared and on what basis?
iv) What new data sources are required?
v) Can any data held be easily integrated into a GIS, i.e. with regard to structure, topology, etc?

vi) What degree of centralization or dispersal might be initially desirable?
vii) Are plans underway to standardize data capture formats within the organization?

6.7.3 What Financial Considerations Should Be Made?

The instigation of any new development will entail costs and these usually need to be the subject of a cost/benefit analysis. It is important, and relatively easy to perform this analysis, but it is very much more difficult to assess the cost savings associated with the intangible advantages that the adoption of GIS brings. It is a good idea to monitor the costs of obtaining all data, so that at least for the future a bank of "cost experience" is being built up.

The actual capital costs of the initial set up will vary with the extent of the GIS application, the size and quality of items purchased and their source. The price range is enormous, varying from <$3 000 for the most basic processor, plus VDU, digitizing tablet, dot matrix printer and software, to >$200 000 for a highly sophisticated complete GIS system. If data is purchased then this can represent a very significant proportion of capital costs. The notional price, in terms of computer speed and memory plus quality of hard- and soft-copy output per unit of money spent, has been falling rapidly since the inception of GIS, and it is likely to do so for the immediate future. An important cost consideration is that developments in all aspects of GIS are occurring so rapidly, that most sub-systems are practicably dated in about five years and obsolete in ten. To keep up to date therefore, depreciation costs ought to be calculated at up to 20% per annum.

Most actual operating costs are quite low and comparable to other office activities though data capture can be very labour-intensive. However, given the sophisticated nature of the activity, the skill and managerial levels of personnel employed may be quite high, so costs here must be carefully considered. Also, in many government organizations new posts will have to be established. Thus, the problem is not only financial, but administrative as well. Burrough (1986) shows a very detailed analysis of personnel/cost inputs, and it is clear that there is a hierarchy which varies according to a general functional classification (from lowest to highest), i.e.:

i) Personnel needed for data input to GIS, e.g. digitizing, attribute entry, checking, inputting satellite imagery.
ii) Personnel needed for data output, e.g. mostly different kinds of plotting.
iii) Personnel needed to use software for data analysis, e.g. performing manipulation and analyze s within the GIS.
iv) Personnel needed for planning and management.

6.7.4 What Sort of GIS Configuration Should We Adopt?

Since space prohibits an analysis of choice considerations pertaining to individual hardware items, we shall restrict our cover of this to a number of pertinent questions. We shall then make a consideration of alternative hardware configurations, realizing that it is difficult to isolate these from GIS cost and software considerations and that in practice it would be possible to configure hardware in an almost infinite variety of ways. The hardware choices cannot be clear-cut and decisions must relate to personal preferences, software choices, functional requirements, capital available, numbers of users, the degree of interaction with other systems, etc., plus the answers derived from some of the earlier questions.

The questions which need answering before investing in hardware include:

i) What are the relative merits of buying a "turn-key" system? (see section 6.7.7)
ii) What formal evaluation methods (benchmarking) should be used to assess hardware suitability?
iii) What after sales service is given and at what cost?

iv) Where can independent advice on hardware or configurations be obtained?
v) How extendable, compatible, or flexible, are the various hardware components?
vi) What is the hardware supplier's overall reputation?
vii) How much storage space is likely to be needed, and how quickly do we need to work?
viii) What quality, size, colour and range of output is required?
ix) Do functional requirements dictate raster or vector data, or a combination?
x) How many users may be accessing the GIS and for what purposes?
xi) How easy is the hardware to use, or the manuals to follow?

GIS configurations are combinations of hardware which, at a minimum allow one user to perform some of the GIS functional range, and at a maximum comprise hundreds of workstations linked to one another, to a complete range of hardware devices and to other computers, and which perform all GIS functions at rapid speeds backed by large memory stores.

Minimum practical configuration requirements can be met from a microcomputer (PC) based interactive graphics workstation. This system typically features a 32 bit processor, hard disk storage, perhaps a tape and disk sub-system, a digitizing tablet, a plotter, alphanumeric keyboard and a high resolution graphic display screen, all of which function together as a single "tool". Since developments in microcomputers have been so rapid, these systems are now capable of running at 4 MIPS (million instructions per second), and of being linked with communication devices into larger networks. Systems management needs to adhere to strict guidelines since regular data back-up is seldom available. Though there are a number of other limitations on PC-based workstations such as poor ergonomics, limited processing power, restricted integrated software availability and difficulties of integrating with other equipment, they must be viewed as a very attractive start-up entry into GIS. Costs vary greatly but rise to about $30 000.

At a more sophisticated level, but using similar configurations, there is the engineering workstation or multi-user centralized system (Figure 6.21). This is based on a minicomputer, to which all the peripherals are connected. Peripheral devices are capable of little or no processing and users are dependent upon the processing power of the host computer and the data base it supports. Costs can be up to $100 000 for a complete functional GIS. They mostly operate under the UNIX operating system, and a vast amount of software covering all applications is available.

Various networks of computers, workstations and other hardware form the next level of configuration. A variation on the centralized single PC, or minicomputer engineering workstation configuration, is to form linkages of either of them based around a central processor, forming what is called a local area network (LAN) (Figure 6.22). Here the peripherals are connected to the LAN through device servers which control processing, and the limited storage problems of the PCs can be overcome by the use of a large external driver. Limitations on these configurations are the dependence on the single processor which affects response times, and the system is less amenable to incremental upgrades.

The definite trend in configuration, caused by technological advances, is towards distributed processing. Here processing power, and usually the GIS data bases, are decentralized across a network of graphics or "dumb" workstations, computer servers, file servers and other peripherals (Figure 6.23). Users have access to all the resources of the entire network and extra processors can be added when desired, as can other peripherals. Workstation nodes can be distributed throughout a large building on a LAN and, where a multi-site operation is desirable, wide area networks (WANs) are possible using microwave transmissions or cable networks for transferring data. This distributed processing approach is particularly efficient because it allows processing power and storage capacity to be available at the user's location thereby decreasing delays in response time. Data is distributed among users via DBMS software which acts as a "master librarian". It is becoming increasingly common to bring additional data into the network from "value added network services" (VANs), i.e. companies who sell digital data via

Figure 6.21 Multi-tasking Centralized Engineering Workstation (from Croswell and Clark, 1988)

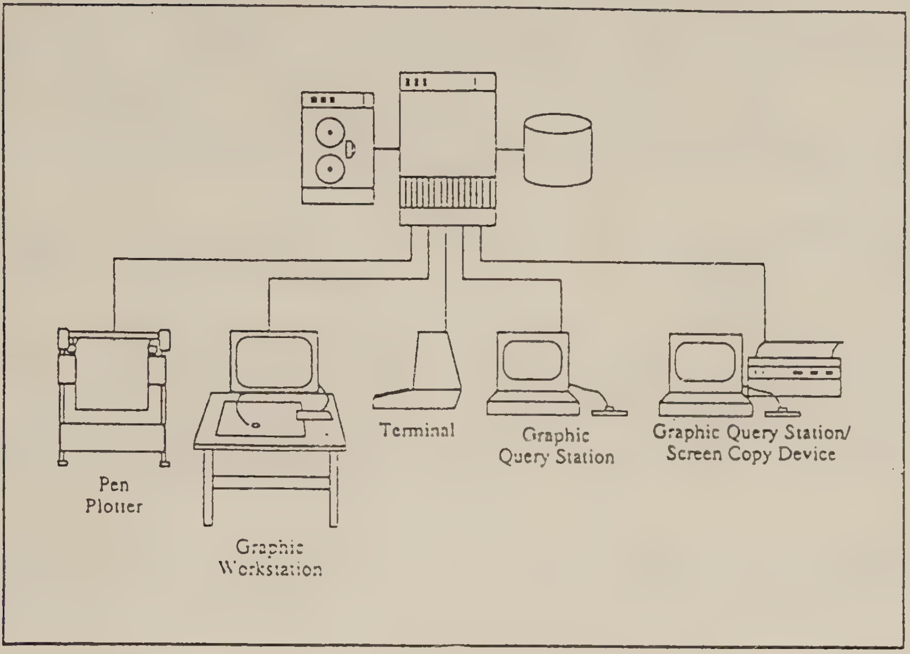

Pen Plotter
Graphic Workstation
Terminal
Graphic Query Station
Graphic Query Station/ Screen Copy Device

Figure 6.22 Centralized Configuration Using a Local Area Network (from Croswell and Clark, 1988)

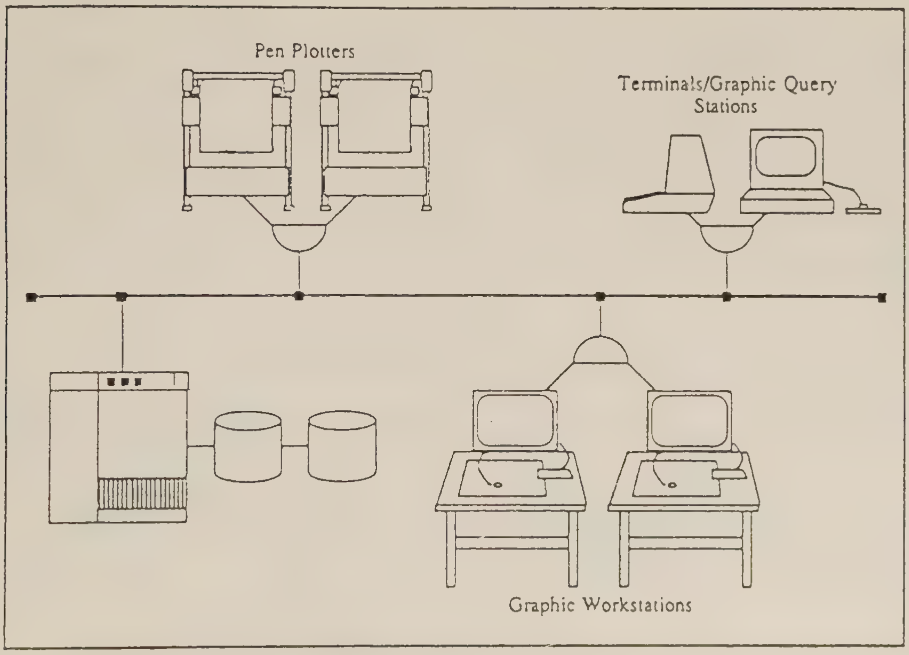
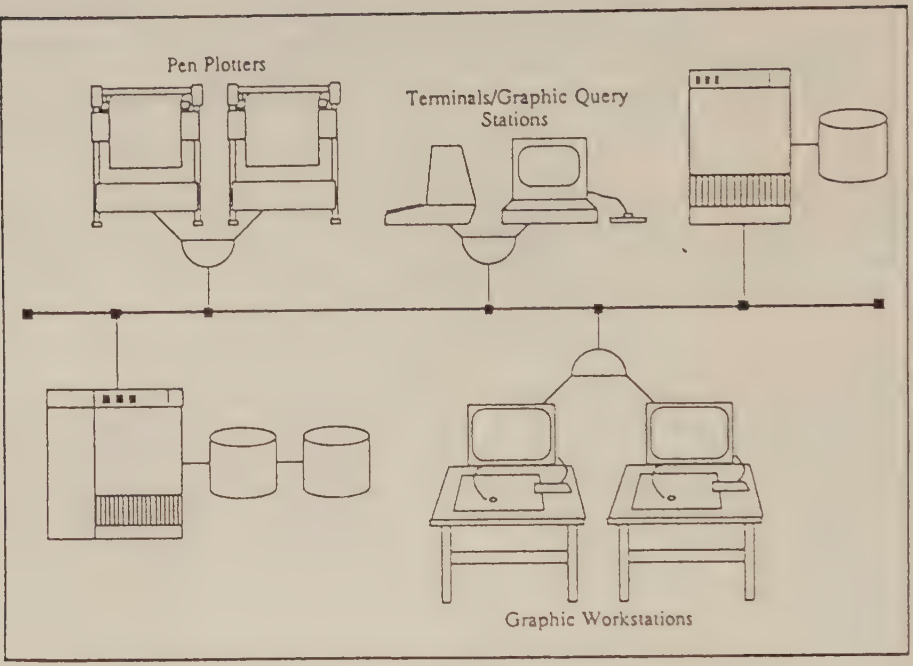

Pen Plotters
Terminals/Graphic Query Stations
Graphic Workstations

Figure 6.23 Multiple Processors and Peripheral Devices on a Distributed Network (from Croswell and Clark, 1988)



public telecommunication lines. Hardware manufacturers are increasingly offering networking capability for all of their products.

This hierarchy of GIS configurations, from small or basic to the large completely functional GIS, should in no way be seen as ranging from "bad" to "good" or from "make do" to "ideal". The choice of configuration is governed by user's needs and, since extremely sophisticated GIS are now available at the lower hierarchical level, then user needs can be increasingly satisfied for a lower capital outlay. What a greater GIS configuration investment means is that the user's actual needs or requirements can be greatly upgraded. But before large investments are made, the user should ask himself whether the extra money would not be better spent in more comprehensive and accurate data collection systems, since they completely govern what the GIS is really capable of.

6.7.5 What Sort of Software Should We Choose?

Since there are now so many packages to choose from, the primary task is to determine which software best fits the operational requirements that have been previously established. It is unlikely that there will be a single best package. If the GIS is to be shared between departments or between operating functions, then it could well be that several more specialized packages will be required. If hardware is already owned then the nature of this, plus its operating system, will influence what software is available.

Some important points that a software purchaser might want to consider are:

i) Which software applications or system interfaces have the highest priority and why? Remember that software packages are often oriented towards providing a specific capability or supporting a specific application area, e.g. CAD, terrain analysis or image processing.

ii) How the graphics are integrated with the attributes. Some systems place more emphasis on the intelligence of the data base describing one or other of these features.

iii) What is the functionality of the DBMS, e.g. how well is a RDBMS able to "join" attribute data stored in one tabular list with that stored in others? Is the DBMS an integral part of the package or is it provided as an optional interface?

iv) Does the software allow for continuous mapping? This is important since "seamless" data base structures are essential to many analytical problems.

v) How secure is the software supplier? - does he have a good record? - are his products known for versatility and reliability?

vi) What kind of graphic user interface is desirable? - simple menus, "pop-up" menus, icons, windowing? - how user friendly is it?

vii) How user-friendly is documentation? Manuals should be perused prior to purchase and if possible test runs of a package should be arranged or viewed.

viii) Do we go for a raster or vector based approach? Though this consideration might be diminishing in importance as software systems more frequently cater for both, it would be important with regard to the structure of the data base sources being used.

ix) Can the software easily be transferred to other GISs?

6.7.6 What Are Our Personnel Needs?

In section 6.7.3 we noted that personnel costs played a significant part in GIS costs, largely because of the skilled nature of much GIS work. In this section we will not look at skill acquisition *per se*; this will be done in section 6.8. Here we shall be concerned with the range of personnel needed.

Since applied GISs seldom function as a large-scale enterprise, then the numbers of personnel employed would be very low. For some of them GIS operations would only form part of their work, e.g. along with other computer work or as part of the management structure. It is likely that any skilled person working full time on GIS would need to be very versatile, i.e. because of the detailed and wide ranging knowledge required of computing, spatial analysis and GIS. In two studies, Kapetsky *et al* (1987) and Kapetsky (1989) it was found that for a GIS operation to be successful a cross-disciplinary team needed to be assembled. For a typical aquaculture study this might comprise a fishery biologist, a systems analyst specializing in RS image processing and GIS, a local fisheries officer, plus personnel to secure local information and information which was typically held in a central location (usually a capital city). Any of these personnel might usefully contribute to setting up a GIS, as well as advising on its further enhancement. Taking a different approach, Burrough (1986) classifies and exemplifies the range of work associated with GIS under two main categories:

1) "Low skills": - to include typists, computer operators, map digitizers, draughtsmen, etc.
2) "High skills": Managers - necessary for both the daily running of GIS and harmonious relationships between GIS and the rest of the organization.

Liaison - necessary to establish and maintain contacts with users.
Technical - to include computer cartographers, programmers and systems development.
Scientists - environmental scientists and others who use GIS for their research and applications programmes.

To obtain personnel with appropriate GIS skills or qualifications, there are a number of approaches:

i) For some of the less-skilled tasks, in-house training might be considered. This may only be a realistic alternative in a large organization where the costs can be more easily absorbed and where there are likely to be staff capable of offering instruction. Alternatively, staff skilled in computer hardware operations must be recruited.

ii) Employ external instructors or send staff away on training courses.

iii) For the more specialized tasks it is almost essential that outside recruiting would be necessary.

iv) If some aspects of the required work was "occasional", then it could be sub-contracted out to specialist companies.

v) If advice was being sought on any GIS matter, then outside consultants could be engaged.

The particular approach to obtaining personnel would vary not only from one organization to another, but also between countries, between functional levels of GIS and on a temporal scale, i.e. with growth in the scale at which the GIS operated.

In staffing a GIS operation any organization will need to consider very carefully its personnel mix, paying particular attention to:

i) What mix of internal and external personnel should be engaged to design or set up the GIS?

ii) Do we initially fully contract out our GIS so as to see its potential?

iii) What GIS jobs might we need to contract out immediately, or in the future?

iv) Can we afford to recruit personnel specifically for GIS work related solely to aquaculture and inland fisheries?

v) Should the application of personnel to aquaculture and inland fisheries GIS be developed from a more general GIS operation?

vi) What particular staffing mix do we need, i.e. between computer specialists and subject matter specialists?

vii) What proportion of our personnel effort should be employed in data collection?

viii) Through what means, and using what criteria, do we recruit our GIS personnel?

6.7.7 Procedures for Setting Up the GIS

We should now be at a stage where a strategy report has been produced so that the organization has a clear idea of the overall objectives for establishing a GIS, has some idea of particular user requirements and desired output and knows what its commitments will be in terms of costs, data and personnel, plus the capital software and hardware necessary to allow the GIS to function at a specified level of sophistication. It should also be clear where or how the GIS will fit into the organization from the operational viewpoint.

Having done this, a quite straight-forward set of procedures should be followed for project implementation, though these may vary between organizations or countries. These are:

i) Look for several suppliers of the necessary software. Nowadays there is a good chance that needs will be met by available packages, though software programs from several suppliers may be needed. A suitably shortened and revised form of the strategy report should be available for potential software and hardware suppliers which clearly sets out the relevant user requirements.

ii) Before purchasing software, it is important to consider the hardware necessary. Software might have been designed to run on a specific machine, or it could run on other computers perhaps with a performance loss.

iii) An alternative to looking at software and then hardware is to consider a "turn key" system, i.e. a combination of soft and hardware put together to satisfy a well identified demand. This could be either a completely "customized" system which is perhaps specialized in certain functions, or it could be an off-the-shelf system. Beware that "turn key" systems can, in practice, carry out all the functions which you have specified. And remember - you may be buying a lot of software capability which you will not require and the hardware may not be easily extendable.

iv) Having narrowed down potential software and hardware suppliers to perhaps two or three serious contenders, each of these should be asked to do a "benchmark" test. This will involve running a series of practical simulations, of the types of functions identified as being important, and then comparing the results against the other suppliers and against quoted specifications. The tests might be on the time taken to perform certain operations, on ease of use or graphics positional accuracy, etc.

v) It should now be possible to choose a system(s) based on price and required performance. The normal rules that apply within an organization for supplies or equipment purchase may then be followed. Once the system has been implemented it might still be necessary to undertake certain tasks in order to maximize GIS usefulness, e.g.

a) Customizing the output to obtain a desired "look".
b) Creating documentation which is specific to the user's GIS.
c) Training personnel to the demands of your system.
d) Looking for suitable, specific data.
e) Carry out a post-implementation audit to see whether the original objectives for the GIS are being met. If not, why not?

vi) Needs such as accommodation, site, workspace size, delivery dates, finance, insurance, personnel, security and communications potential and facilities should be worked out as an ongoing operation during the project evaluation and implementation stages. Other operational considerations which should also have been considered include planning for the ongoing management of the system, maintenance of the data bases, suitable storage conditions for expensive tapes, provision of back-up tapes or disks, work scheduling arrangements and data acquisition procedures.

6.8 Guidance and Support for GIS

It is fair to say that the range of support, information and guidance in GIS was at a minimal level until the mid-1980s, although it was commensurate with the lower profile which GIS then had. With the technological-led boom in GIS, which had its seeds in earlier research and which was aided by the synthesis of scientific fields which were combining around the power of the processor, i.e. CAD, RS, computer graphics, spatial analysis, etc., then support for and from the "industry" took off rapidly. Confirmation of this is to be had in the introduction of new courses, the inception of journals and magazines, the increase in conferences and symposia, the inception of GIS learned societies, and so forth, all of which have occurred in the past three or four years. Unlike RS, where support has come from a fairly narrow range of interested groups and companies, interest in GIS is far wider. Here we can only hope to point the reader along some major lines of support - this should be sufficient given the amount of information which is now available.

6.8.1 Training in GIS

Undoubtedly there is a chronic shortage of people with the necessary skills in all aspects of GIS. This has arisen, not only because of the enormous upsurge of demand, but also because of the necessity of having such a wide knowledge base to be truly efficient in all the complexities of GIS. People having these skills have easily been able to secure promising careers, usually in the private sector, and consequently the areas of research and teaching have been very hard hit (Dept. of Environment, 1987; Green, 1987; Gittings, 1989).

In response to these needs a large number of short courses on GIS are now being offered, both by the software houses and university departments. These are typically of three to five days duration, expensive, and are aimed at either an "intensive introductory" level for management, or for introducing new additions or updates to software packages.

University departments or Higher Education Colleges are rapidly introducing GIS into their syllabuses, mainly as part of undergraduate (first degree) Geography or IT courses, or as a typically one year part-time course, or as a specialized one year Masters degree or Diploma. Some detailed curricula, setting out all the essential components or a GIS course at degree level, are now beginning to appear, e.g. Unwin and Dale (1990). Many of the GIS courses have evolved from sideways moves out of IT, RS, CAD or geography or from an integration between any of these fields.

Another kind of short course has been offered by FAO. It is a GIS and RS appreciation workshop with the objective to familiarize fisheries and aquaculture personnel from developing countries with applications and constraints of the two technologies. Workshops have been from 8 to 15 days and include field verification of RS and GIS results. The Global Environmental Monitoring System of the United Nations Environmental Programme (UNEP) also offers GIS courses for developing-country persons, but of a longer duration and aimed broadly at the environment.

One response to the lack of teaching staff in GIS has been the computerized tutor. There are two recent developments:

i) Geographical Information Systems Tutor (GIST), developed in the U.K. at Birkbeck College (Raper and Green, 1989). This tutorial program is structured in a logical functional sequence, and uses illustrated "hypercards" to explain the fundamentals of GIS. Browsing is possible in any sequence, and GIST can either be accessed through a wide area network or it can be purchased.

ii) Geographic Information Starter System (GISTARS), developed at Penn State University in the USA (Myers, 1990). This is a training package aimed at promoting interest in, and understanding of, GIS technology in developing countries. It runs on PCs having one or more disk drives and a CCGA card.

6.8.2 Published Information on GIS

This can be conveniently listed under three major categories:

A) Conferences and Symposia. These are organized by a variety of learned societies. They usually occur annually, where they might be associated with an exhibition or trade show, and they invariably produce conference proceedings. International ones include:

i) International AUTO-CARTO.
ii) International Automated Mapping and Facilities Management.
iii) International Geographic Information Systems.
iv) International Geosciences and Remote Sensing Symposium.
v) International Symposium on Computer Assisted Drawing.
vi) International Symposium on Spatial Data Handling.
vii) Private companies, or some governmental organizations in the USA, are now holding annual conferences/symposia, e.g. GRASS, ESRI, ERDAS, GIMMS, etc., which are "marketed" internationally.

B) Journals and Trade Magazines. Few of these are totally concerned with GIS, though all of the others have a rapidly increasing GIS component, and some have issued special GIS editions. Table 6.7 lists the main ones. The trade magazines, though sometimes showing company bias, are excellent sources of information, typically offering articles plus "Trade Directories" under such headings as Training, Software Suppliers, Hardware Suppliers, Consultants, GIS Specialist Services, etc.

Table 6.7 The Main Journals or Trade Magazines Covering GIS

i) The Cartographic Journal.
ii) Cartographica.
iii) Computers and Geosciences.
iv) G.I.S. World.*
v) Geo-Processing.
vi) ITC Journal.
vii) International Journal of Aerial and Space Imaging, Remote Sensing and Integrated Geographical Systems.
viii) International Journal of Geographical Information Systems.
ix) Mapping Awareness.*
x) Mapping Sciences and Remote Sensing.
xi) Photogrammetric Engineering and Remote Sensing.
xii) Photogrammetric Record.

* = Essentially trade publications (as are the books marked below)

C) Books. Very few books have been devoted solely to GIS - the list below includes all those currently available.

i) ASPRS (1987).
ii) Aronoff (1990).
iii) Burrough (1986).
iv) Dept. of Environment (1987).
v) Foster and Shand (eds) (1990).*

vi) GIS World Inc. (1989).*
vii) GIS World Inc. (1990).*
viii) Masser and Blakemore (Eds) (1990).
ix) Mutunayagam and Bahrami (1987).
x) Peuquet and Marble (Eds) (1990).
xi) Rhind and Mounsey (1991).
xii) Shand and Moore (Eds) (1989).*
xiii) Star and Estes (1990).
xiv) Tomlin (1990).

6.8.3. Other Sources of GIS Guidance

These are necessarily rather a mixture, and make no claims to being comprehensive. They include:

i) *Private companies.* Notably the software houses publish extremely useful newsletters, typically two to four times per year. These are an essential way of not only promoting themselves, but also of detailing the rapid developments which are occurring. They nearly always offer back-up services and guidance on software problems.

ii) *Cartographic and Digital Archives.* These are being compiled in some countries, but because formidable problems are faced regarding updating, legal ownership of data, storage responsibility and location, access rights and costs, etc., then progress in building up digital map archives is slow (Finch and Rhind, 1987). UNEP now offers on-line access to a catalogue of environmental digital data sets including details of the responsible agencies. Further details can usually be had from national mapping agencies or national libraries, and the FAO retains an archive of their digitized resources.

iii) *Consultants.* Some consultants specializing in GIS are beginning to emerge, and their availability is best sought through those previously mentioned trade magazines or books, or through specialist consultancy directories.

iv) *Videos.* A number of videos have recently been produced which look at GIS from varying perspectives. Recent ones are reviewed in Hall and MacLennan (1990).

v) *Computer On-line Facilities.* If these are accessible, then a wide range of bibliographic data can be acquired. This may be a very rapid way of acquiring details on published information, though the full texts may not be so easy to obtain.

vi) *National GIS Organizations.* Some of these have been formed in the last two or three years with a view to consolidating and coordinating progress in GIS. They include:

a) National Centre for Geographic Information and Analysis. (U.S.A.)
b) The Association of Geographic Information. (U.K.)
c) Canadian Centre for Geographic Information Systems in Education.
d) National Centre of Expertise for Geographic Data-Processing. (Netherlands).
e) Centre for Spatial Information Systems. (Australia).

6.9 Future Trends in GIS

"We are convinced that a fundamental change towards the routine use of geographic data on computers has already begun. The consequences of this cannot be predicted except in general terms and by analogy. The introduction of computer accounting systems 25 years ago was hesitant at first and many mistakes were made. However, costs fell, the value of new forms of information from the systems was discovered and, in due course, these systems became commonplace in quite small organizations. A return to manual systems is now inconceivable. We believe the use of Geographic Information Systems will develop in a similar fashion."

(Dept. of Environment, 1987). Despite the fact that GIS faces huge research programmes and countless problems, we feel it right to preface the conclusion of our analysis of GIS in an optimistic way.

In a field which is moving as fast as GIS, it is imperative to review future trends, if only to see the kind of scenario which we may be facing in as little as half a decade. Some of the trends we mention will have been previously hinted at, especially in section 6.6.2 on problems in GIS, so we have not elaborated on these. The reader must be aware that research advances are also being made in many related disciplines, some of which will have a profound effect on GIS - especially those developments occurring in basic computer technology. Useful sources on future trends in GIS include: Clarke (1986), Wilkinson and Fisher (1987), Croswell and Clark (1988), Rhind (1988), Tomlinson (1989) and Ventura (1989) and Maguire (1990). From the hundreds of possible trends we have selected 20 of the most important:

1) The ability to handle both raster and vector data on the same machine, at the same time and to inter-relate them. It is inevitable that intensive research will be aimed at gaining the many advantages to be had from achieving this integration (Wilkinson and Fisher, 1987).

2) The development of "intelligent" or "expert" knowledge-based systems. These are based on formal sets of rules which may be modified and systems which are capable of learning from experience. Basically, this means that a great deal of time, or digital storage space, could be saved if during the encoding, manipulation or retrieval stages of GIS functioning, the program was able to use logical rules (knowledge) in specific situations to short-cut, improve or restructure its procedures, e.g. searches were not carried out for areas outside certain prescribed domains (Rhind, 1988; Molenaar, 1989), or in digitizing there might be automated recognition of certain features on maps by colour or symbols. Expert systems will also aid users in making decisions over which GIS functions to use under particular circumstances (Butler, 1988).

3) The display of maps, or other graphical data, will be made more effective to the final users. There has been insufficient constructive research into the whole area of map perception (visualization), even though it is clear that map presentation techniques are sometimes an obstacle to understanding what the GIS is trying to convey. Wilkinson and Fisher (1987) claim that the future acceptance of GIS may depend just as much on the quality of the visual product as on their capabilities for manipulating spatial data.

4) How to deal with the "fuzziness" of data. Fuzzy data derives from it being ill-defined or having limited accuracy. Research is in progress to find out when to use which kind of measurement to assess data inaccuracies, and Butler (1988) describes other work aimed at providing a rigorous basis for expressing "fuzziness" concepts.

5) How do GIS users use the available data? It is clear that if two analysts were requested to separately seek an answer to the same specific questions using any available objective data, they would be likely to arrive at different solutions. Why is this? It must be related to the sorts of questions asked in seeking a solution (selection criteria), to perceptions of levels of importance, to imperfect knowledge, etc. We need to be precise about what operations should be performed on what data, which data is the most important under specified conditions, which mathematical functions can be legitimately performed and perhaps to revise our data gathering priorities. Tomlinson (1989) clearly outlines research priorities in this area.

6) The need for a "Geographic Information Theory". By establishing such a theory, Molenaar (1989) claims that the GIS user would be better able to understand its possibilities, to structure the data processing sequences, to formulate criteria for measuring the performance of a system and to design a GIS from scratch.

7) The incorporation of "desk-top publishing" into GIS. This means that software packages (or programs) would be integrated into the GIS in order to greatly improve, and to

control, the quality of the output, e.g. integration of maps and text, layout and appearance of maps, variations of fonts, improved colouring or shading, etc. (Schokker, 1989).

8) Developments in optical disk storage systems. They will have a large impact on GIS because of the ability to store huge volumes of information in a small, inexpensive format. Storage densities are between 10 and 50 times greater than traditional magnetic storage devices. Until recently the technology was used mostly for "write once read many" (WORM) processes since data could not be erased. This is still very useful for data archiving where huge data volumes must be stored and retrieved, but rarely changed, e.g. map outlines. However, erasable optical disk units are just becoming available (Crosswell and Clark, 1988) and these are likely to become the norm for large-scale storage by the mid-1990s.

9) Move towards a "World Referencing" or "Global Positioning" system. Whilst this seems almost essential for organizations such as FAO, which operate at the world scale, it will also greatly ease the data transference problems in other fields such as ocean monitoring, meteorology, international fisheries, pollution evaluation and control - in fact any field which breaches international borders. Global positioning satellites will help make referencing easier and hopefully a Global Positioning system will be in place during the next decade.

10) The development of high-speed telecommunications facilities. This will aid the development of efficient networking at local and national scales, allowing access to data bases over a wide distance which will be vital to many GISs. This development will require great advances, not only in network design and implementation, but also in the standardization of GIS data formats and structures.

11) The development of wholly different and more efficient data base structures. This will inevitably involve the implementation of a knowledge-based DBMS which incorporates intelligent query languages to help the GIS user rapidly retrieve required items of data. The whole area of DBMSs, and data base storage facilities, will become increasingly visible as the number of data bases and their size dramatically increases. Tomlinson (1989) maintains that we need to develop geographic data models which will allow investigations of the complex linkages which occur in any spatial area, in order to improve the ways in which data bases are designed and structured. In the meantime, Goodchild (1988) indicates that work on both hierarchical and relational data structures or models continues to bring new ideas.

12) Improvements in both automatic and semi-automatic data capture by raster scanning and line following techniques. More sensitive scanners will allow greater discrimination between data and "noise". It is likely that paper maps of the future will incorporate special inks or bar codes to make feature recognition easier for automatic data capture equipment. There will eventually be transaction-activated data capture, where the processes of change themselves generate updated data bases.

13) There will be renewed attention to the updating of algorithms. Many existing ones were devised with limited objectives, levels of functionality and "computational elegance".

14) Tomlinson (1989) asserts that there is not yet much potential for existing GIS software to carry out quantitative spatial analyses, i.e. considering that many of the methods are very useful, they are simple and they have been around for up to 30 years. Examples include factor analysis, modelling network changes and location optimizing routines.

15) Clearer definitions in legal ownership and copyright laws relating to the use and transference of data, and to the legal liability of the producer of data when users act upon advice and something goes wrong.

16) Making graphic user-interfaces more friendly. Much GIS software is still too difficult for novices to use, but in the near future users will be able to "drive" systems by using concepts and terms which are familiar to them.

17) The formulation of GIS standards to facilitate information exchange. Proposals for minimum and uniform standards have been laid down in some countries (NCDCDS, 1987), but world-wide a great deal needs to be done. Standards need to apply to both the quality of the data and the way it is structured, so that levels of expected accuracy can be realistically proposed.

18) Much work urgently needs to continue on error propagation - on the ways in which uncertainties in the values of control parameters and input data affect results.

19) How the GIS user can be made aware of the digitized data which exists. There is much work to be done in creating directories, archives, on-line facilities, etc., which catalogue clearly the availability, location, cost and rights to existing digitized data.

20) A continuation of the massive task of digitizing existing topographic, and some thematic, maps. This will also encompass data improvements and up-dating and will perpetuate discussions on "which levels of government will provide which type of commonly used data in which digital format?" (Tomlinson, 1989. p.292).

CHAPTER 7 - SOME CASE STUDIES SHOWING APPLICATIONS OF REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS TO AQUACULTURE AND INLAND FISHERIES

Our case studies are intended to give as wide a review as possible of recent examples of the practical applications of RS and GIS to aquaculture and inland fisheries. Although we attempted to balance the studies proportionately between RS and GIS and between aquaculture and inland fisheries, it was difficult to do the latter since few RS or GIS studies have been specifically directed towards inland fisheries. In lieu we have selected some relevant applications which look at various properties of the lake environment. A few of our case studies are not directly related to either aquaculture or inland fisheries, but they are included so as to give an idea of the potential which could be applied to those fields. We have concentrated where possible on studies relating to the developing world, since we feel that this is where these examples can most usefully apply. The RS studies are placed first, followed by the GIS studies, and then the one study which covers both - within these areas of RS and GIS the aquacultural studies precede the "others" studies. Finally, we have attempted to structure the content of most case studies in a similar logical sequence.

Study 1

TITLE: "The Preselection of Sites Favourable for Tropical Shrimp Farming"

AUTHOR: CNES - IFREMER

PUBLICATION and DATE: IFREMER - *France Aquaculture.* 1987.

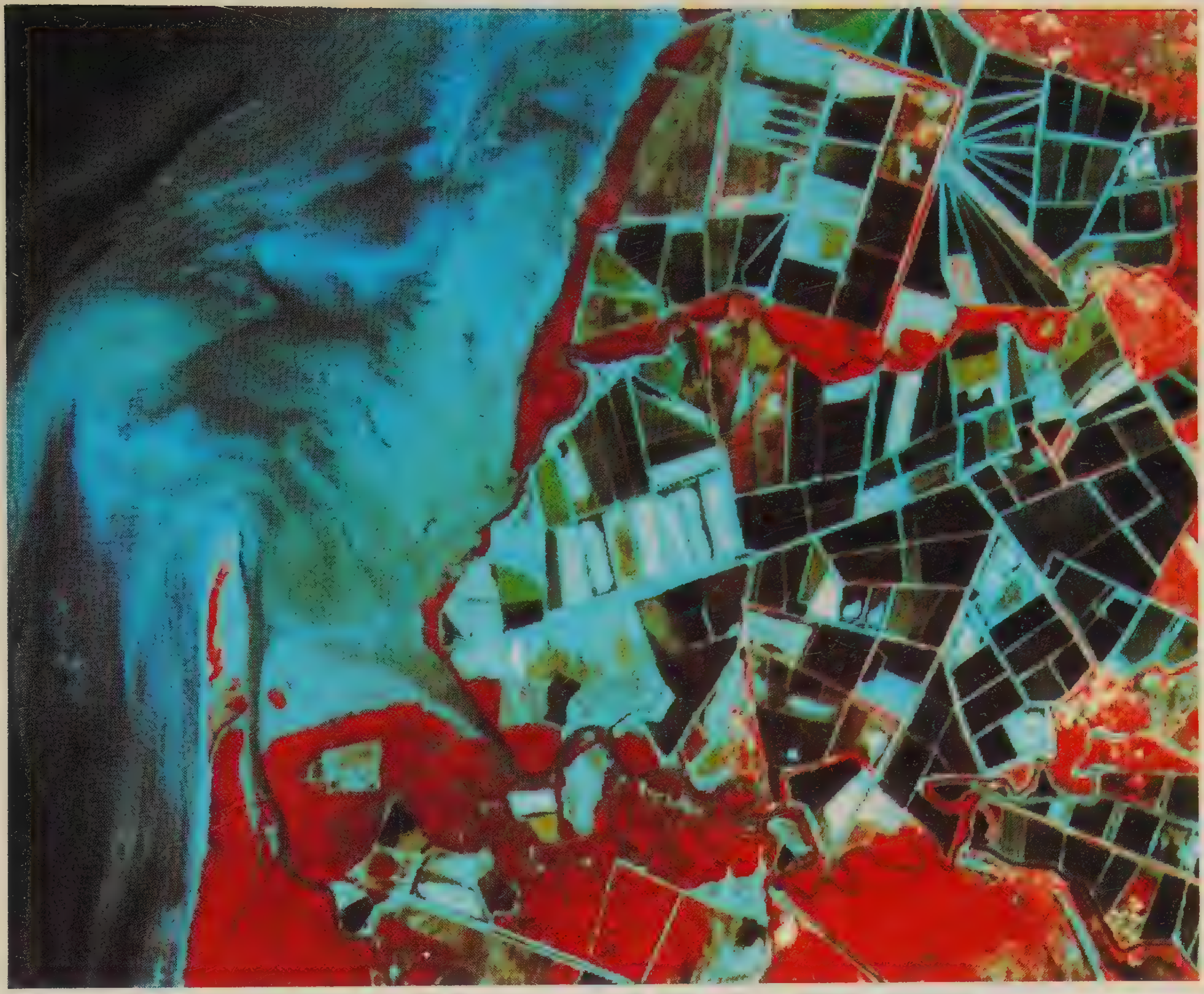
Introduction/Objectives

The French Institute of Oceanographic and Coastal Studies (IFREMER), together with the National Centre for Space Studies, CNES), are interested in promoting the use of SPOT satellite imagery for improving aquatic resource use and for coastal management generally. They have produced a quantity of promotional materials, much of which is devoted to aquaculture. The above publication is not written in great detail but it has been included since its images are clear and very relevant to mariculture. Further details on the value of SPOT to coastal resources can be found in Loubersac (1988).

Tropical prawn culture has been the most actively developed sector of world mariculture over the past decade. During this period production has doubled every two to three years. The farming of prawns and shrimp is being developed mainly in tropical areas. About 70% of the current world production, which totals 350 000 tons, is produced in S.E. Asia. South and central America produce most of the rest and production has expanded more in Ecuador recently than in any other country.

Many tropical areas tend to have complex coast/land interfaces, typically consisting of low lying silty and sandy soils, often covered with dense mangroves and interspersed with channels, rivers, distributaries, marsh, lagoons, etc. This has meant that mapping has been difficult and/or cartographic standards have been poor. For both intensive and semi-intensive commercial shrimp and prawn production, extensive flat areas are required where large earth ponds can be excavated. These need to be connected via a series of water channels to a salt water source - frequently a sheltered estuarial or deltaic environment. Figure 7.1 shows a SPOT false colour image of a typical network of ponds in Ecuador. The dark ponds are those in production (having deeper water), the light blue are presently empty (having shallow water) and the red is permanent land.

Figure 7.1 SPOT Image Showing Shrimp Ponds Near Guayaquil, Ecuador



Methods/Equipment

The criteria for site selection and assessment of potential involve complex considerations of meteorological, hydrological, geomorphic and socio-economic factors. However, as IFREMER state, the necessary secondary data sources are not always available, or they are out of date; the relevant coastal features are either not on the maps or they are inaccurate, and in certain tropical countries aerial flights are either forbidden or made impossible by bad weather. Hence the advantages of satellite RS imagery.

Figure 7.1 gave a very clear indication of how existing sites can be imaged by SPOT. Clearly, for the purposes of preselecting sites it would not be practicable to produce images at this scale on a world wide basis. Figure 7.2 shows an image of the S.W. coastal area of New Caledonia, having an original scale of 1:150 000. Potential sites for shrimp production have been circled. Various image enhancement and enlargement processes would then be performed on the digital data covering these areas. Figure 7.3 shows an example of this, where the Bouches du Diahot area (seen in the top right circle on the Figure 7.2 image) has been enlarged to a scale of 1:25 000, and land use colouring has been applied. Any of the areas indicated with vertical black lines would be worthy of further ground inspection and more detailed site assessments.

Figure 7.2 SPOT image showing preselection sites for aquaculture in part of New Caledonia

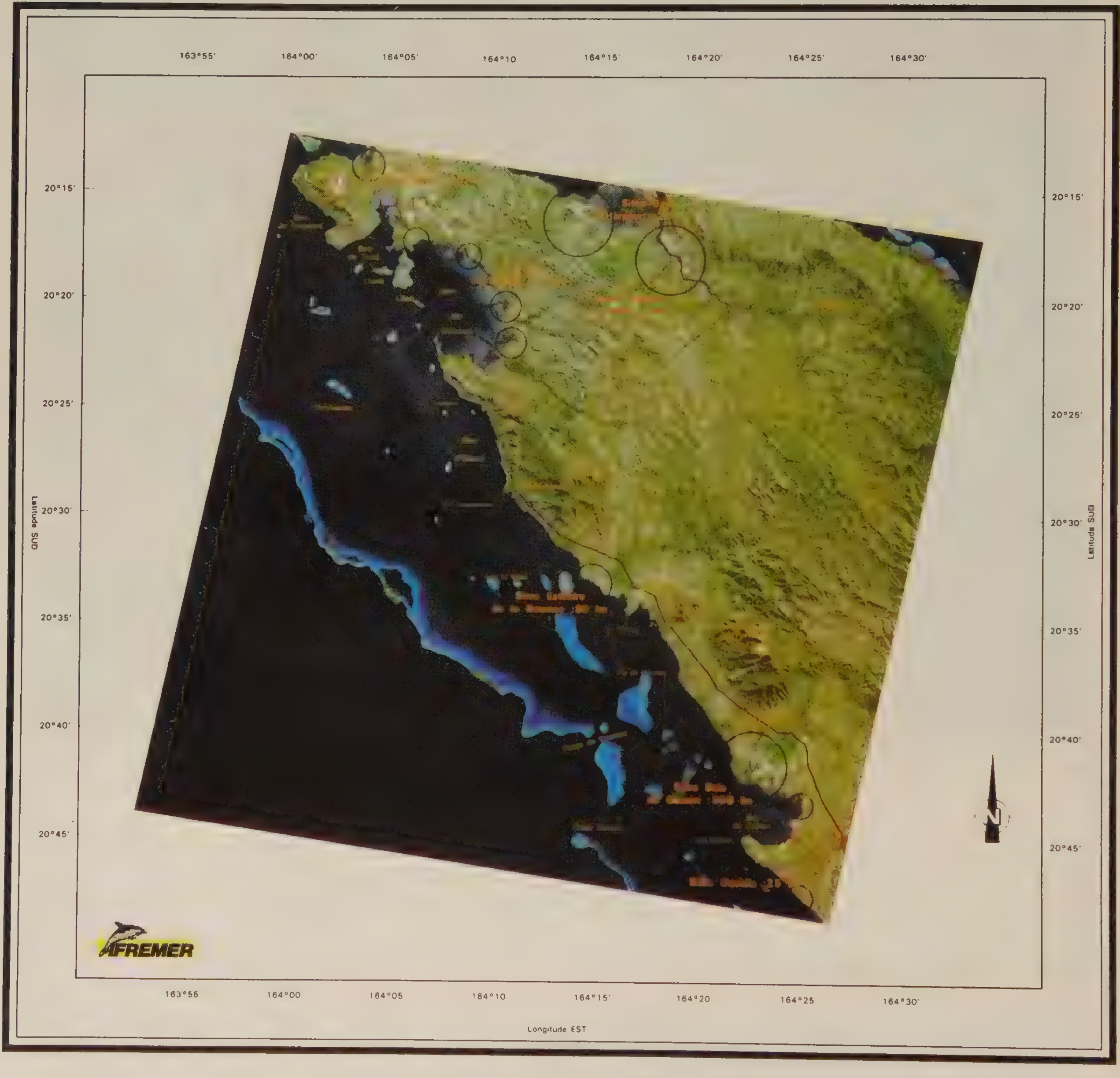
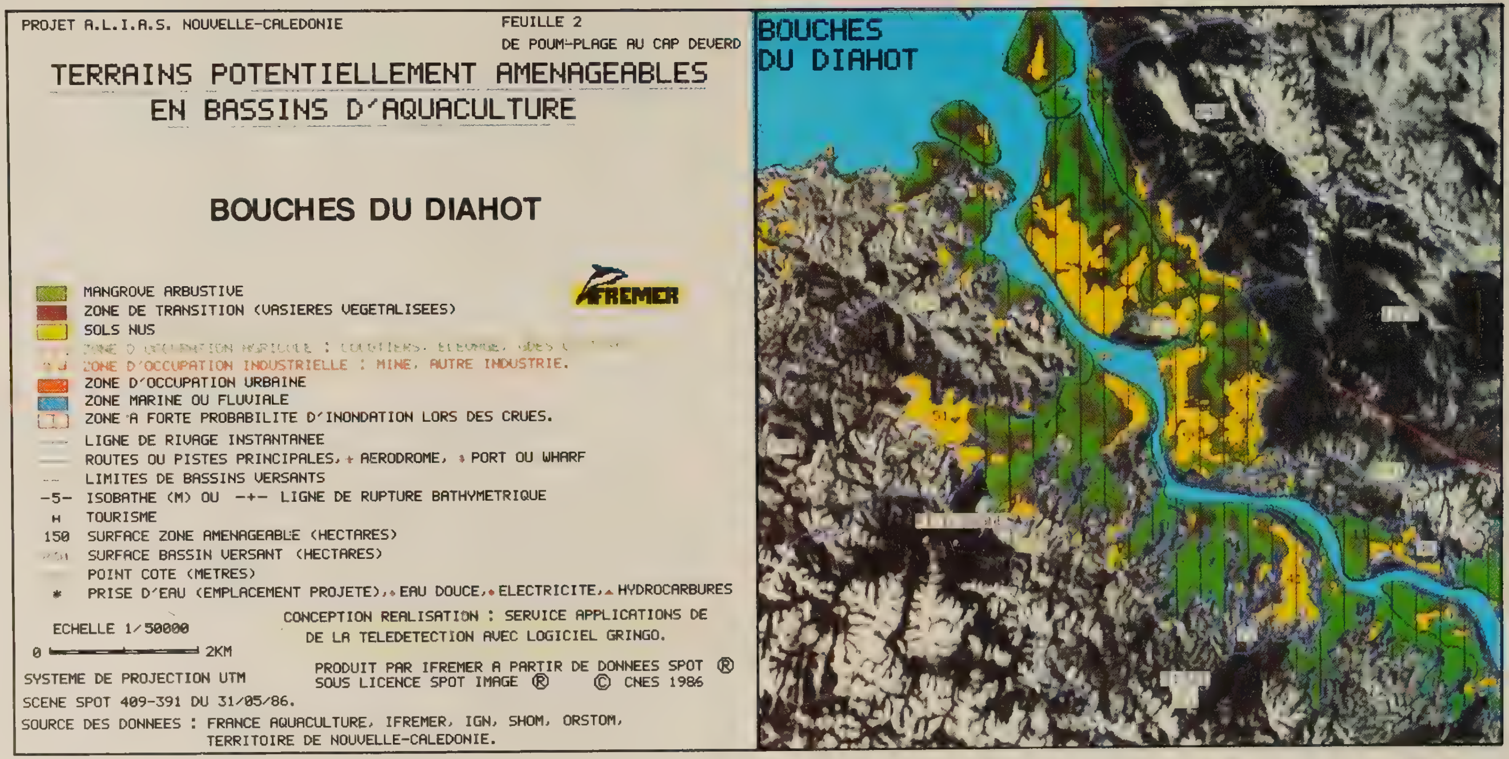

163°55'
164°00'
164°05'
164°10
164°15'
164°20'
164°25'
164°30'
20°15'
20°20'
20°25'
20°30'
20°35'
20°40'
20°45'
Latitude SUD
N
IFREMER
Longitude EST

Figure 7.3 Enlargement of a SPOT Image Showing the Bouches du Diahot Area of New Caledonia in Detail


PROJET A.L.I.A.S. NOUVELLE-CALEDONIE
FEUILLE 2
DE POUM-PLAGE AU CAP DEVERD
TERRAINS POTENTIELLEMENT AMENAGEABLES EN BASSINS D'AQUACULTURE
BOUCHES DU DIAHOT
IFREMER
MANGROVE ARBUSTIVE
ZONE DE TRANSITION (VASIERES VEGETALISEES)
SOLS NUS
ZONE D'OCCUPATION AGRICOLE : CULTURES, ELEVAGE,
ZONE D'OCCUPATION INDUSTRIELLE : MINE, AUTRE INDUSTRIE.
ZONE D'OCCUPATION URBAINE
ZONE MARINE OU FLUVIALE
ZONE A FORTE PROBABILITE D'INONDATION LORS DES CRUES.
LIGNE DE RIVAGE INSTANTANEE
ROUTES OU PISTES PRINCIPALES, + AERODROME, PORT OU WHARF
LIMITES DE BASSINS VERSANTS
-5- ISOBATHE (M) OU -+- LIGNE DE RUPTURE BATHYMETRIQUE
H TOURISME
150 SURFACE ZONE AMENAGEABLE (HECTARES)
SURFACE BASSIN VERSANT (HECTARES)
POINT COTE (METRES)
* PRISE D'EAU (EMPLACEMENT PROJETE), EAU DOUCE, ELECTRICITE, HYDROCARBURES
ECHELLE 1/50000
0
2KM
CONCEPTION REALISATION : SERVICE APPLICATIONS DE DE LA TELEDETECTION AVEC LOGICIEL GRINGO.
SYSTEME DE PROJECTION UTM
PRODUIT PAR IFREMER A PARTIR DE DONNEES SPOT ® SOUS LICENCE SPOT IMAGE ® © CNES 1986
SCENE SPOT 409-391 DU 31/05/86.
SOURCE DES DONNEES : FRANCE AQUACULTURE, IFREMER, IGN, SHOM, ORSTOM, TERRITOIRE DE NOUVELLE-CALEDONIE.
BOUCHES DU DIAHOT

Results/Conclusions

The availability of real time and precise geographic data for identifying site potential is offered by imagery such as SPOT. This data can lead to exact locational positioning and to precise aerial quantification - a positive aid to decision-making. The digital form of this data allows for analysis under a huge array of circumstances, at selected scales varying from 1:20 000 to 1:400 000. IFREMER claim to have a selection of images for all tropical coastal areas available and, since SPOT imaging has now been in progress for more than four years, temporal analysis of coastal developments are already possible. Where airborne sensing is not possible, or where it is not easily available, then clearly the resolution achievable by SPOT is sufficient for identifying potential locations for shrimp culture. For understandable reasons, this promotional material fails to mention the additional potential which digitized SPOT imagery would have as source data for a range of more complex GIS investigations. And, although the type of "map" which Figure 7.3 represents, is a valuable and up to date aid, far more data is needed before a realistic site selection process can be accomplished.

Study 2

TITLE: "Feasibility of Using Remote Sensing to Identify the Aquaculture Potential of Coastal Waters"

AUTHORS: Cordell, E.V. and Nolte, D.A.

PUBLICATION and DATE: Published by Recon Technologies, Inc. 1988.

Introduction/Objectives

This study is included for several reasons. It is one of the very few examples where RS, and a limited amount of GIS, has been applied directly to aquaculture. It is also extremely detailed and there is an accompanying publication - a User's Guide to Remote Sensing which is even more detailed ! Because the study is so extensive, we could not do justice to it if we were to review it in the normal way. Instead we will review Chapter 5 only (using the headings given by the authors). This chapter is what is called an "Interpretation" of the results of the study.

Overall, the study aims to see how useful RS imagery can be to resource allocation in a remote, but valuable, location where other means of investigation would be time consuming and therefore costly. To provide a focus for the study, the specific aquaculture category of Pacific oyster rearing was chosen. The area chosen was S.E. Alaska; more specifically the Etolin island area. This area is remote from major population centers, mountainous and forested; there are numerous inlets and small islands; steep slopes cause many landslides and the high rainfall leads to a significant freshwater run-off with consequent turbidity. The natural water conditions are frequently ideal for oyster growth and a number of commercial farms operate in nearby island groups.

Information gathering from remote sensing

For marine environment applications, RS can provide information on:

i) Sea temperatures.
ii) Suspended sediments (turbidity).
iii) Water colour (which reflects plankton concentrations).

iv) Sea ice.
v) Shallow water bathymetry (water clarity factor).
vi) Sea conditions (wave direction, wave length).
vii) Land use (clear cuts, landslides, erosion, point-source pollution, cultural areas).
viii) Sea surface vegetation (kelp beds).

Variables in remote sensing

There are several factors which can influence the quality of RS images and can affect whether or not they are even worth acquiring, e.g.

i) *Weather*. The percentage of cloud cover causes most problems, especially in areas of high precipitation or where sea fogs are frequent.

ii) *Smoke*. This is frequently a problem in forested areas.

iii) *Time*. The time of day can affect the quality of the image, e.g. the amount of water vapour in the air, and darkness can be the best time to acquire water temperature data. Shadow length can be problematical for very early or late daytime imagery.

iv) *Sensors*. Some do not operate over certain areas, e.g. if there is no on-board recorder and ground stations are "out of view". Many sensors have restricted working hours in order to save power and they may only orbit over an area once or twice a month.

v) *Sensor performance*. Sensors are prone to their particular "quirks" which the image analyst should be familiar with.

The imagery interpretation process

The authors set up an imagery interpretation process (Figure 7.4) which they activated upon receipt of each photographic image. Flawed images, or those having too much cloud cover, were rejected and alternatives sought. If images were good, and resolution was adequate, then information on turbidity was plotted onto a base map using either a zoom transfer scope or interpolation. Information on ice was compiled in the same way; other features such as land-use could be similarly plotted. If the scale was poor, then image enhancement using optical magnification was used. If the imagery features were difficult to see, then optical filters were used. These simple, low-cost techniques were able to detect much information on turbidity flows in the study area, and to a more limited degree, the presence of sea ice. Sea conditions were mapped using NASA U-2 colour infrared imagery. This data, along with land mass configurations, was utilized to predict areas with shelter from possible rough sea conditions.

Some comments on individual imagery were given:

i) *Landsat*. This was in 9 x 9 in. positive transparencies which provided information on suspended sediment loads. When the positive transparencies were processed into negatives, so that enlargements could be made, it was noted that the reversed colours of the negative displayed the sediment better than the original positives. The quality was good but the ground resolution (at 1:1 000 000) was poor.

ii) *SPOT*. This imagery was received as a positive transparency at a scale of 1:250 000. The quality was good but it had limited utility. The spectral characteristics prevented it from detecting any sediments and, as the image was acquired at high tide, it proved to be of little value for determining shallow water depths. It did detect ice formations and provided data on land use activities.

iii) *Advanced Very High Resolution Radiometer (AVHRR).* This imagery was in negative format and of good quality. It revealed water temperature differences in the study area. Resolution was poor with the smallest area of temperature difference being detected at 1.1 km^2.

iv) *Heat Capacity Mapping Mission (HCCM).* Imagery from this sensor was in negative format and of good quality. However, since it only revealed gross water body temperature differences, its utility was limited.

v) *Coastal Zone Colour Scanner (CZCS).* CZCS imagery was received in negative format. Its resolution was even worse than the HCCM and AVHRR. The images had extensive cloud cover so they proved to be of little value.

vi) *Alaska High Altitude Aerial Photography (AHAP).* This colour IR imagery was acquired from a NASA U-2 aircraft and was in positive transparency format. It provided vast amounts of data on suspended sediments, wave directions, water currents, land use activities, shallow water bathymetry and it provided locations of stream outlets to the shoreline. It was the most cost-effective source of RS data.

Figure 7.4 RS Image Interpretation and Analysis Processes

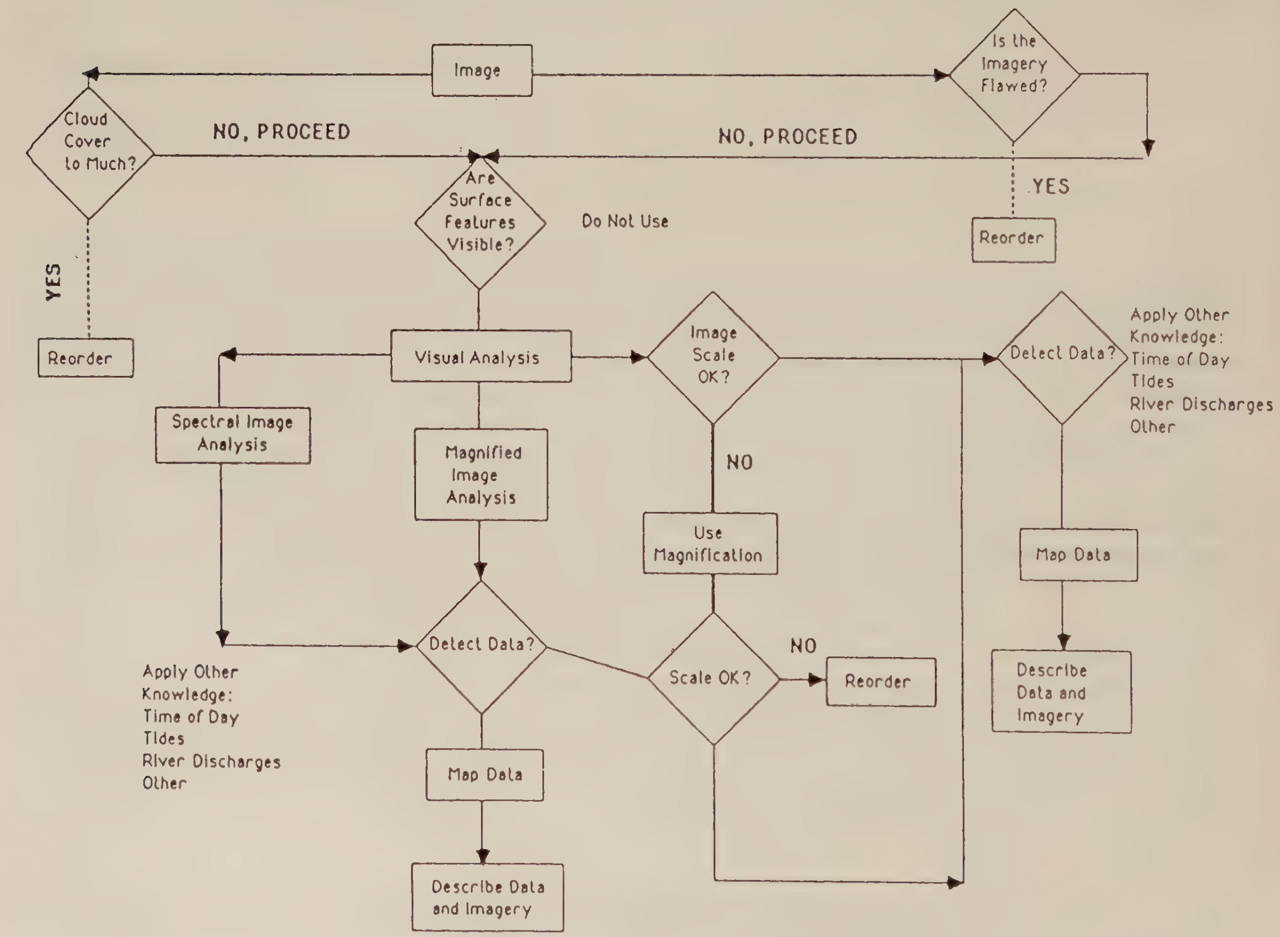


Image
Is the Imagery Flawed?
Cloud Cover to Much?
NO, PROCEED
NO, PROCEED
Are Surface Features Visible?
Do Not Use
YES
Reorder
YES
Reorder
Visual Analysis
Image Scale OK?
Detect Data?
Apply Other Knowledge:
Time of Day
Tides
River Discharges
Other
Spectral Image Analysis
Magnified Image Analysis
NO
Use Magnification
Map Data
Describe Data and Imagery
Detect Data?
Scale OK?
NO
Reorder
Apply Other Knowledge:
Time of Day
Tides
River Discharges
Other
Map Data
Describe Data and Imagery

Testing remote sensing imagery data validity

If the imagery interpreter is unfamiliar with an area, there are certain techniques that should be adopted in order to reduce image interpretation errors. Ideally the interpreter should research and read as much information as possible about the study area prior to actual interpretation, or ground (or water) truthing might provide a more accurate interpretation aid. The authors point out the costs involved in ground truthing and suggest that a sampling frame should be used.

The use of AutoCAD as a database

To compile the data from the various sources of information, the following problems had to be overcome:

i) Different scales of maps, charts and imagery.
ii) Different coordinate systems.
iii) Different units of measurement.
iv) Different types of data.
v) Be able to update, delete or reproduce the data.

There are several manual methods of overcoming these problems. These were briefly described, though they were rejected because of the many time-consuming difficulties which were involved and because there are now PC automated design programs which allow the necessary mapping adjustments to be made.

The system used in this study was AutoCAD, using an IBM PC/AT with 40 megabyte hard disk memory, a digitizing pad and an HP plotter. All of the data sets were standardised (registered) to a selected base map outline, a version of which is shown as Figure 7.5. The UTM projection was selected, and all measurements were metricated so that AutoCAD could function efficiently and so that the data base structure was simplified. Digitizing was then performed and data bases were created for the following "layers":

i) The shoreline of the study area.
ii) Bathymetry.
iii) Turbidity.
iv) Kelp bed zones.
v) Sea ice.

The authors then describe some of the various manipulation functions which AutoCAD could perform, plus the assigning of labels and feature attributes. The program Surfer was used to draw a 3D view of the Stikine Strait area. This view (Figure 7.6) clearly shows the steep under-water topography and therefore the area's unsuitability for oyster development.

Site selection

In order to prioritize the many factors that determine the suitability of a location for oyster culturing, a scoring technique was suggested. The factors scored in a preliminary example were:

i) Size of area (not too small or too large).
ii) Depth of water (an average, in meters).
iii) Turbidity in the area.
iv) Presence of sea ice (winter window).
v) Shelter from high seas or current.

The scoring, as applied to four sites which were selected to test the methodology, is shown in Table 7.1.

Figure 7.5 Base Map of Etolin Island Showing Selected Oyster Sites and Turbidity Zones

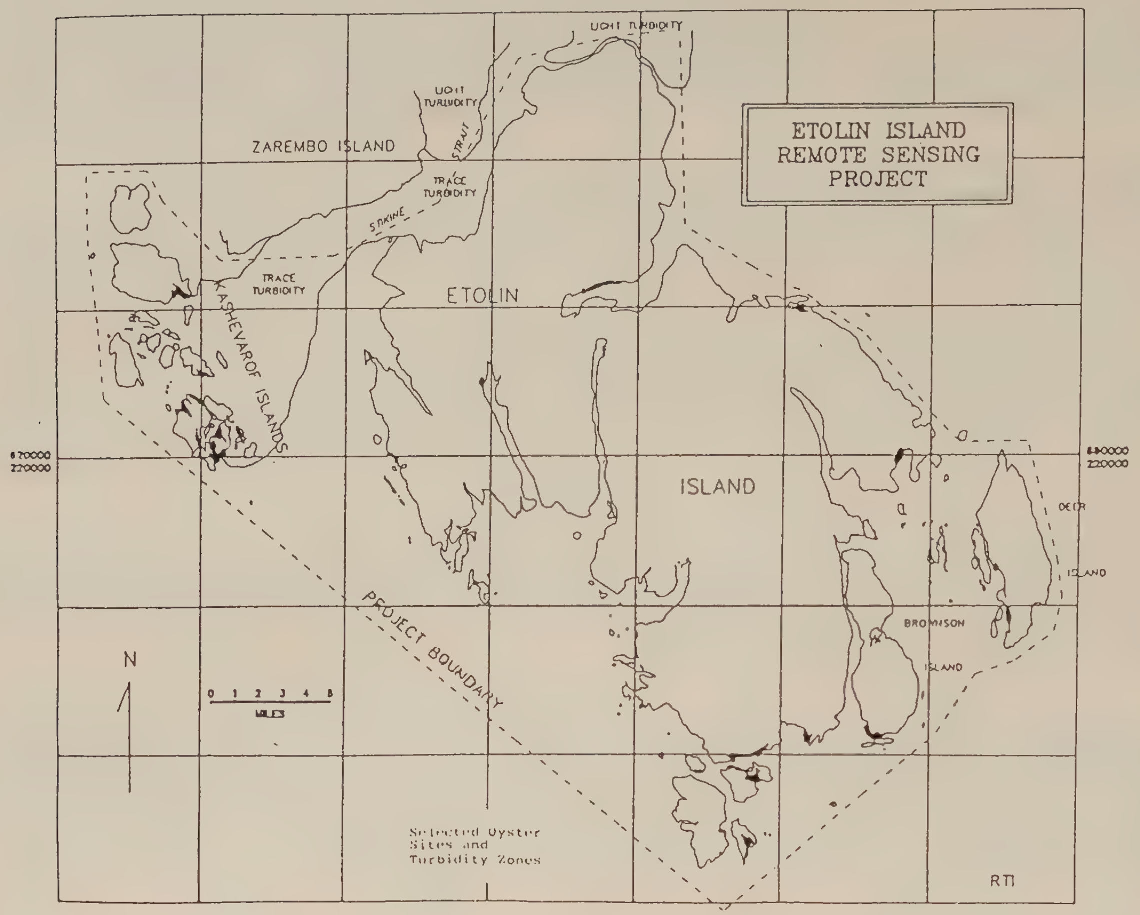

LIGHT TURBIDITY
LIGHT TURBIDITY
ZAREMBO ISLAND
STRAIT
TRACE TURBIDITY
STIKINE
TRACE TURBIDITY
ETOLIN ISLAND REMOTE SENSING PROJECT
ETOLIN
KASHEVAROF ISLANDS
670000
220000
220000
ISLAND
DEER ISLAND
BRONNSON ISLAND
PROJECT BOUNDARY
N
0 1 2 3 4 5
MILES
Selected Oyster Sites and Turbidity Zones
RTI

Figure 7.6 Bathymetry of Stikine Strait Area Looking S.W.

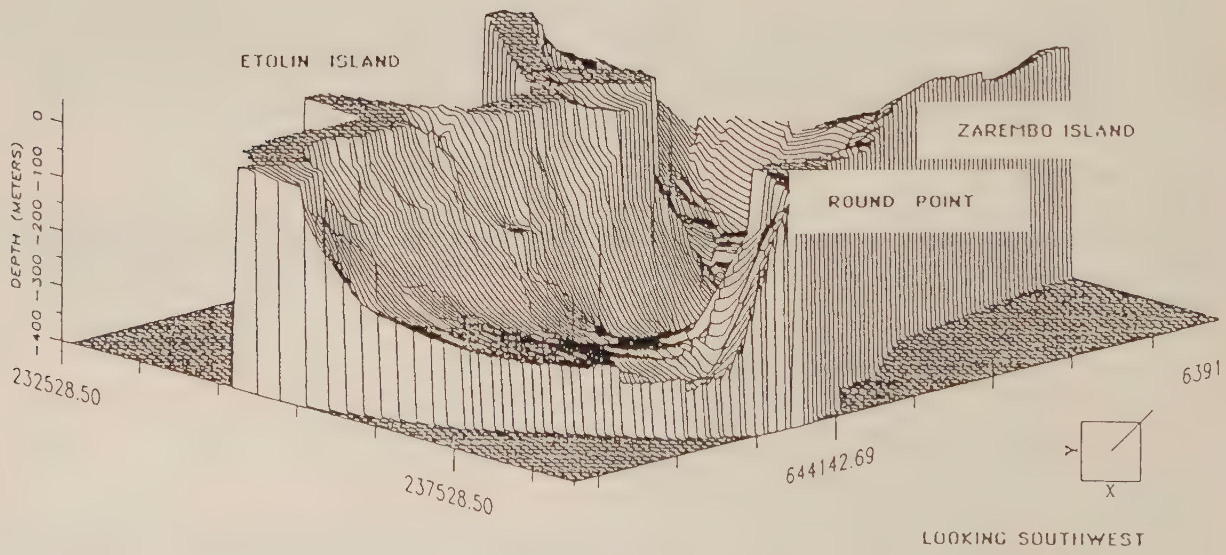

ETOLIN ISLAND
ZAREMBO ISLAND
ROUND POINT
DEPTH (METERS)
0
-100
-200
-300
-400
232528.50
237528.50
644142.69
6391
Y
X
LOOKING SOUTHWEST

Table 7.1 Site Selection Matrix Showing Suitability for Oyster Culture

Site	Area Size	Mean Depth	Turbidity	Sea Ice	Shelter	Total Score
Blashke Island	3	4	3	3	3	16
Stikine Strait	2	1	1	3	1	8
Anita Bay	3	2	4	3	2	12
Jadski Cove	3	4	4	2	3	18

Factor Scoring

1. Area Size:
   1 = < 1 hectare
   2 = 1 to 2 hectares
   3 = > 2 hectares

2. Mean Depth:
   1 = < 5 meters or > 20 meters
   2 = 20 to 15 meters
   3 = 15 to 10 meters
   4 = 10 to 5 meters

3. Turbidity:
   1 = moderate turbidity (summer)
   2 = low turbidity (summer)
   3 = slight turbidity (summer)
   4 = no turbidity (summer)

4. Sea Ice:
   1 = winter sea ice
   2 = possible sea ice
   3 = no sea ice observed

5. Shelter:
   1 = occasional high seas possible; two sides protected
   2 = rare high seas; three sides protected
   3 = protected on four sides

Results

Table 7.1 shows that, using the criteria listed, the areas around Blashke Island and Jadski Cove appear well suited for the development of oyster culture. The lack of suitability of the Stikine Strait area is well identified. However, other siting criteria might well want to be considered such as:

i) Proximity to marine wildlife habitats.
ii) Local sea temperatures.
iii) Conflicts with existing or future land uses.
iv) Proximity to freshwater outflow.

Using the existing criteria for site selection a number of additional areas were identified as being suitable for oyster culture and these were listed.

This section of the study concluded with a list showing the estimated accuracy of using the AutoCAD software, plus a comment on some of the additional statistical data which was produced.

Study 3

TITLE: "Remote Sensing and Model Simulation Studies of the Norwegian Coastal Current During the Algal Bloom in May 1988".

AUTHORS: Johannessen, J.A., Johannesses, O.M. and Haugan, P.M.

PUBLICATION and DATE: *The Nansen Remote Sensing Center.* Technical Report No.16. September, 1988.

Introduction/Objectives

We will mainly concentrate on the RS aspects of this study, which have also been detailed in Petterson (1989).

There have been an increasing number of so-called "red tides" reported globally during the last decade. They constitute unexpected blooms of algae, some of which are toxic such as the Chrysochromulina Ipolylepis, which may occur in oceans, seas or lakes. The particular bloom reported above occurred during May - June, 1988 in the Skagerrak - Kattegat area of Scandinavia. It was thought to have been the result of the following environmental conditions:

i) Changes in the normal water circulation patterns in the area, resulting in lower rates of water exchange.
ii) Unusually large concentrations of nutrients in the area.
iii) Anomalous high water temperatures and low salinity levels.
iv) Enhanced river run-off in early spring due to mild conditions.

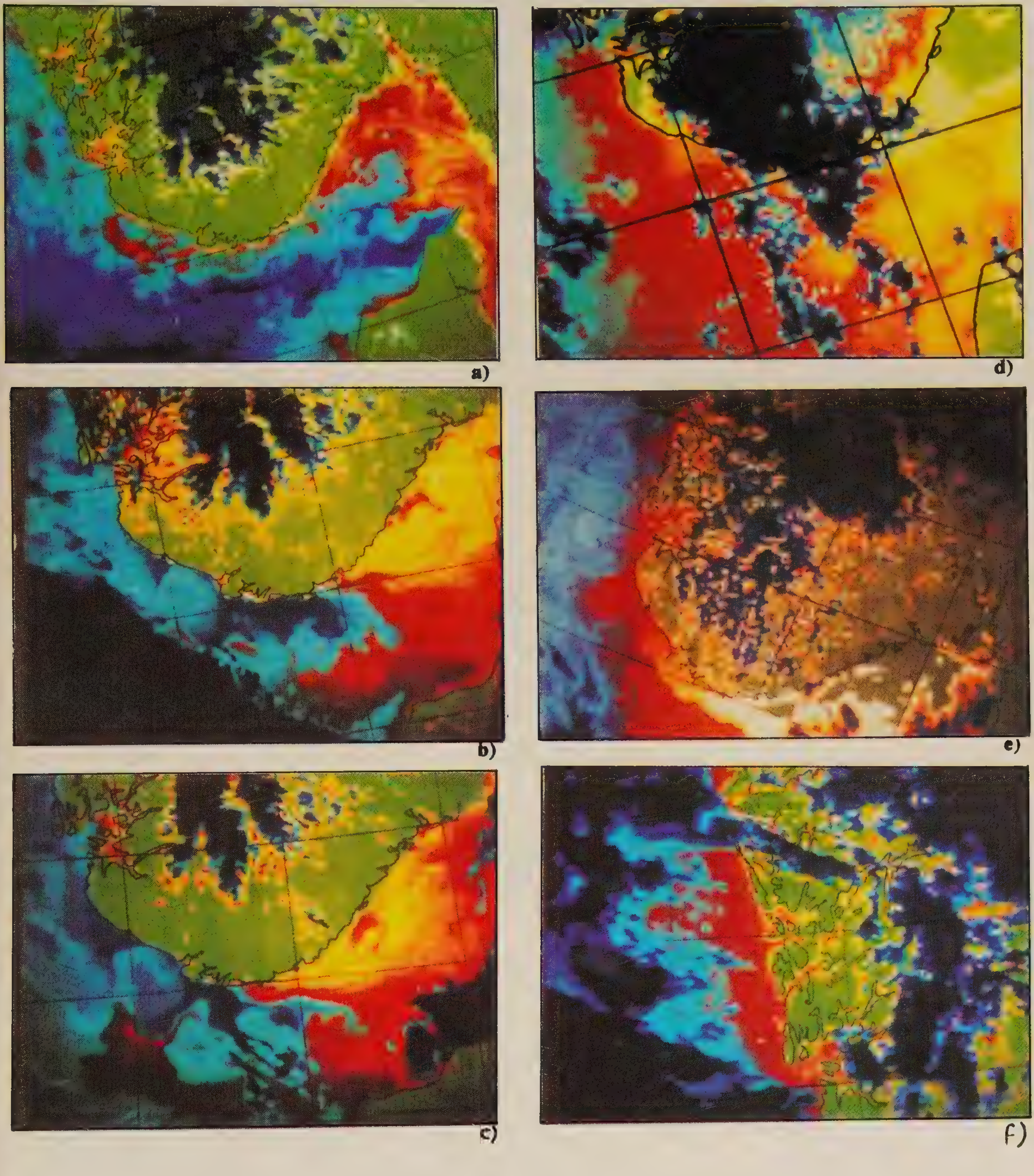
For four weeks the bloom moved eastwards from southern Sweden, along the southern and south-western Norwegian coast. It caused major fish kills to both wild and caged fish. About 480 tons of caged fish (mostly salmon) worth over NOK 30 million were lost, and some 200 marine fish farms were evacuated during the bloom, usually to brackish, inner fjord waters. The study aims to show how the blooms can be detected, using either airborne or satellite sensors, and how a temporal study of bloom movement can enable modelling of future movements, both in an ongoing bloom situation and in any subsequent bloom occurrences.

Methods/Equipment

The Norwegian State Pollution Authority carried out daily air patrols over a 10-day period, covering the coastal region between Oslo and Bergen. The airplane was equipped with a Side Looking Airborne Radar (SLAR), which had proved to be capable of detecting ocean fronts (the leading edges of bodies of warm or cold water). A visual colour monitoring of the bloom and the front was possible (from the aircraft) in calm sea conditions, which eliminated the necessity for ground truthing. Two other aircraft took part in the monitoring, though for shorter periods. They were both equipped with infrared (IR) sensors, which were capable of detecting temperature differences in the surface water, and they confirmed that the bloom was advancing westwards along with warmer water.

Advanced Very High Resolution Radiometer (AVHRR) data from NOAA 9 and 10 weather satellites were received at Tromso satellite station. These data contained information on the sea surface temperature. The data tapes were sent to the Nansen Remote Sensing Center (NRSC), and about 6 hours after the satellite pass, the corrected and processed images were able to give information on the sea surface temperature distribution and the advection and movement of the ocean fronts (Figure 7.7). The temperature and frontal information were used as inputs in the NRSC numerical model of the ocean circulation in the region.

Figure 7.7 Sequence of NOAA Infrared Satellite Images Showing Development of an Algal Bloom Over the Skagerrak in 1988



*NOAA infrared satellite images resolving the surface temperature in the Skagerrak and along the southern coast of Norway during the spring algal bloom in 1988. Images are respectively from May 15 (**a**), 21 (**b**), 22 (**c**), 27 (**d**), 30 (**e**), 31 (**f**). **Color code:** Yellow: warm water ≈ 10°C, Red ≈ 8°C, Blue: colder water ≈ 5°C, Green: land and warm water (on May 27) > 10°C, Black: Clouds and snow in the mountains. The algal front followed mainly the warm water temperature front around the southern coast of Norway, before it culminated on May 29.*

(Images processed at Nansen Remote Sensing Center).

Results/Conclusions

During the first stages of the bloom, observations indicated a close correlation between the algal front and the satellite-derived surface temperature front. The spreading and advection of the algae was thus indirectly monitored by RS infrared data during cloud-free periods. Figure 7.7 shows a large amount of warm surface water (yellow to red = >8C) in the central Skagerrak. Whilst the warm water was confined to eastern Denmark and the eastern Skagerrak during late April and early May, it gradually covered the entire Skagerrak between 15 and 30 May. No similar evolution is observed in the central North Sea, where the mean surface temperature remains nearly constant as represented by the dark to light blue colours.

A combination of airborne, satellite RS and *in-situ* observations were able to closely monitor the movement of the bloom, noting its speed and any "eddies" and "meanders" in the algal front. Meanders in coastal ocean movements are caused mainly by bathymetric variations, i.e. usually topographic ridges.

Discussion/Recommendations

The experience from the operational forecasting during this algal bloom demonstrated the need for improved understanding of the connection between the chemical, biological and physical mechanisms steering the plankton distribution. For monitoring of the algae, the airborne observations were important on cloud covered days when the satellite sensors gave no surface information. However, the lack of airborne RS instrumentation capable of mapping the algal distribution limited the benefit of aircraft surveillance. It is likely that the Synthetic Aperture Radar (SAR) and Radar Altimeter (RA) instruments to be carried on ERS-1 will prove valuable in providing weather independent measurements of ocean circulation patterns, especially in areas such as Norway which has a high cloud frequency. The unexpected occurrence of this toxic algal bloom, accompanied by huge losses to the sea farming industry and the local ecological system, clearly demonstrate the need for a marine or coastal monitoring system based upon real-time extensive RS imagery.

Study 4

TITLE: "Satellite Remote Sensing to Locate and Inventory Small Water Bodies for Fisheries Management and Aquaculture Development in Zimbabwe"

AUTHOR: Kapetsky, J.M.

PUBLICATION and DATE: *CIFA Occasional Paper No.14*. F.A.O. 1987.

Introduction/Objectives

Fisheries and aquaculture in artificial impoundments (small water bodies - SWBs) in Zimbabwe appear to have excellent development potential. It has been estimated that the total surface area of the SWB is between 21 000 and 45 000 ha (Kenmuir, 1981). At an average assumed yield of 300 kg/ha, a total of about 7 000 tons of fish could be produced in these SWBs each year, i.e. if the surface area were only 21 000 ha. This could make an important contribution to the overall supply of fish in Zimbabwe. Among the fundamental questions to be answered by this survey were:

i) How many water bodies are there?
ii) Where are they?

iii) What is their size distribution?
iv) What amount of water do they maintain during the dry season?
v) Are their present uses compatible with fisheries and aquaculture?
vi How productive are they biologically?

If answers can be found to these questions it would be possible to devise a plan for fisheries and aquaculture development in SWBs.

The objective of this study was to show how satellite RS could be a rapid, cost-effective means of providing this required information on SWBs, using Zimbabwe as a test area. Specifically, the study includes the following elements:

i) Identification and inventory.
ii) Size distribution.
iii) Change in surface area between rainy and dry seasons.
iv) Land use or land form context in which SWBs are located.
v) Water colour as an indication of aquatic productivity.

We will not give equal consideration to these elements since we are primarily concerned with showing the use of RS.

Methods/Equipment

The study was based on the visual analysis of two Landsat Thematic Mapper images of N.E. Zimbabwe (Figure 7.8), one corresponding to the end of the dry season (August, 1984), and the other to the end of the rainy season (April, 1985). Each image covers an area of about 32 400 km^2. In order to enhance not only the SWBs, but also to identify them in the context of landforms and land uses in which they occur, three bands were used together. Colour composites of Bands 1 (water turbidity), 3 (terrestrial vegetation) and 4 (water) were made. In order to facilitate the location and identification of SWBs alone, separate images of each date were prepared using only Band 5. Each image was printed in the form of a false colour photograph (Bands 1, 3, 4) or a black and white photograph (Band 5) at a 1:250 000 scale.

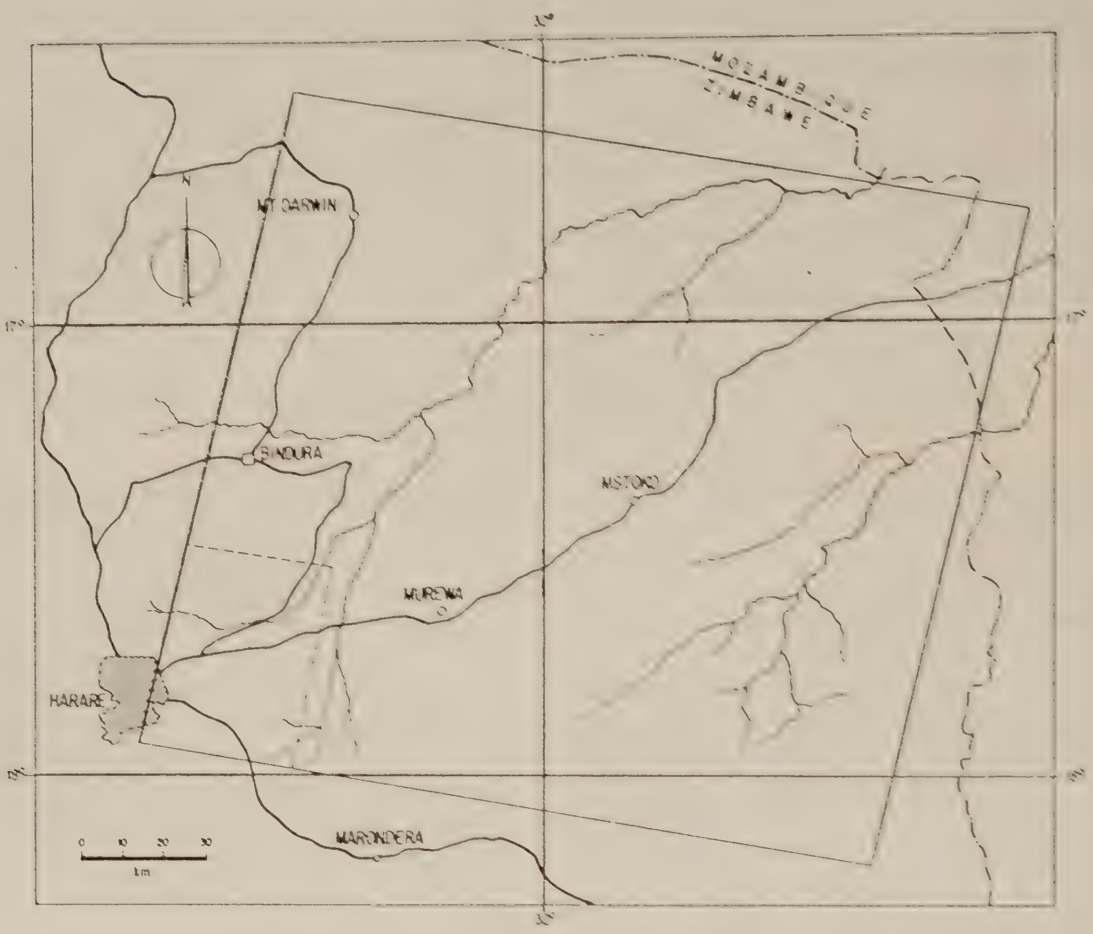
Using the rainy season colour composite, water bodies were identified and circled on a mylar overlay. Criteria for identification were drainage context, shape, character of the surrounding area and colour. A magnifying glass was necessary to verify many of the small water bodies. The mylar overlay was transferred to the black and white (Band 5) image and water bodies not visible on the colour composite were located and circled.

In order to estimate surface areas and changes in surface areas, the same SWBs were located on the dry season image and the change in surface area was calculated. Surface areas were estimated using a dot grid overlay. Each dot represented an area of 4.44 ha. No attempt was made to estimate partial dots. In this same sample the hue of each water body was noted to provide an indication of turbidity, which may suggest levels of aquatic productivity.

Results/Conclusions

In total, 906 water bodies were identified on the rainy season image, i.e. within the area covered by the RS image (shown in Figure 7.8). 82% of the water bodies were associated with intensive agriculture, 13% with rangelands (including some cropland) and the other 5% with rugged highlands. Their total aggregate area, as measured from the satellite imagery was about 10 000 ha. The highest density of SWBs was also associated with intensive agricultural land, i.e. approximately 9 SWBs per 100 km^2. The density of SWBs in rugged highland areas was only 0.6 per 100 km^2.

Figure 7.8 Area of N.E. Zimbabwe Covered by Landsat Thematic Mapper Image



To analyze changes in SWBs from the rainy to the dry season, a small area of the main map was used, i.e. immediately to the N.E. of Harare (see Figure 7.8). Here, the surface areas of 43 SWBs were estimated on both the dry season and rainy season images. Based on rainfall data for the 1983/84 to 1985/86 rainy seasons, it can be inferred that most water bodies were full or nearly so when the April 1985 imagery was acquired. In contrast, the August 1984 image coincided with the end of the previous dry season which was itself preceded by a rainy season of less than 600 mm total rainfall. Thus the August imagery can be taken to represent the minimum water surface remaining at the end of the dry season. At the end of the rainy season 42% of the water bodies are less than 4 ha, and 23% are between 4 ha and 9 ha in size. The total water surface area in this part of the image was 475 ha. Of the 43 SWBs measured in the rainy season image, only 32 could be found on the August dry season image. The total surface area of these SWBs was 244 ha, an overall decrease of 49%.

In practice, only the colour of the larger water bodies could be discerned by visual methods. Of the 14 SWBs in this category, half were black indicating a minimum of turbidity or productivity, four were dark grey suggesting a small amount of turbidity, one was grey, one was green perhaps indicating relatively high organic turbidity and the other was light blue suggesting high levels of inorganic turbidity.

Discussions/Recommendations

The results of this study indicate that satellite RS can be valuable in locating and counting SWBs for potential fishery and aquaculture development, i.e. if the advantages of the technology are fully utilized and its limitations understood. As a means of checking the final results, Kapetsky compared his findings with Kenmuir's 1981 study, in which aerial photographs were used. The comparisons are shown in Table 7.2. There are several causes for differences between the RS and aerial photo results. Because of the small scale of the RS imagery (1:250 000), it is likely that many of the smallest water bodies (<1 ha), were not included. Also, the images might have been gained at different seasons, i.e. Kenmuir's images are not dated. Furthermore, the satellite-derived estimates are taken from a slightly different area and finally, with the satellite images there is a possibility for misidentification. As a follow-up, ground verification is required to obtain a better estimate of the reliability of the results.

Table 7.2 Comparison of SWBs Found in N.E. Zimbabwe Using Satellite and Aerial Photography

	Satellite (Kapetsky)	Air Photos (Kenmuir)
Number of SWBs located in area	43	77
Total estimated area (ha)	485	673
Mean area of SWBs (ha)	11	8.7
Area range (ha)	4 to 53	0.8 to 45

Because of the comprehensive coverage of the country and good quality of the imagery, the use of satellite RS for the detection of SWBs in Zimbabwe is technically feasible. Visual analyses would be less costly than computer processing, but at the same time would limit the scope and utility of results. A combination of Landsat MSS and TM data would satisfy technical requirements and also be cost-effective. Should they be available from other studies, aerial photographs or SPOT imagery could be used to supplement the Landsat data.

Study 5

TITLE: "Use of Remote Sensing in the Study of the Changing Shoreline of Sarykamysh Lake"

AUTHOR: Nuriddinov, O.S.

PUBLICATION and DATE: *Mapping Sciences and Remote Sensing*; Vol.26, No.1. pp74-77. 1989.

Introduction/Objectives

This is one of a number of recent papers showing the use of RS to monitor changes in lake size or shape. This particular study was selected because of its uniqueness in that a huge lake has been inadvertently created by man's interference with the hydrological cycle and, as will be shown, the lake now constitutes a viable inland fisheries resource. Studies showing lake size fluctuations over time could be vital for the successful implementation of inland fisheries development, and the main objective of this study was to test the feasibility of using RS photographic images to study the shoreline dynamics.

The use of extensive irrigation systems in parts of Soviet Central Asia are dramatically altering the surface and sub-surface water balances in the region (Sigalov, 1986). One of the largest reservoirs in the region, the Sarykamysh Lake, has gradually been forming and expanding since 1961 when wastewater from excessive irrigation began accumulating in a large natural depression near the delta of the Amu Dar'ya river which flows into the Aral Sea. It is estimated that between 1961 and 1972 some 18 km^3 of water flowed into this depression to create the lake, and a further 30.8 km^3 of inflow occurred between 1973 and 1980. The water balance of the lake during the 1970s was such that 53% of the incoming water evaporated, 6% was lost to infiltration and 41% went to further filling the lake.

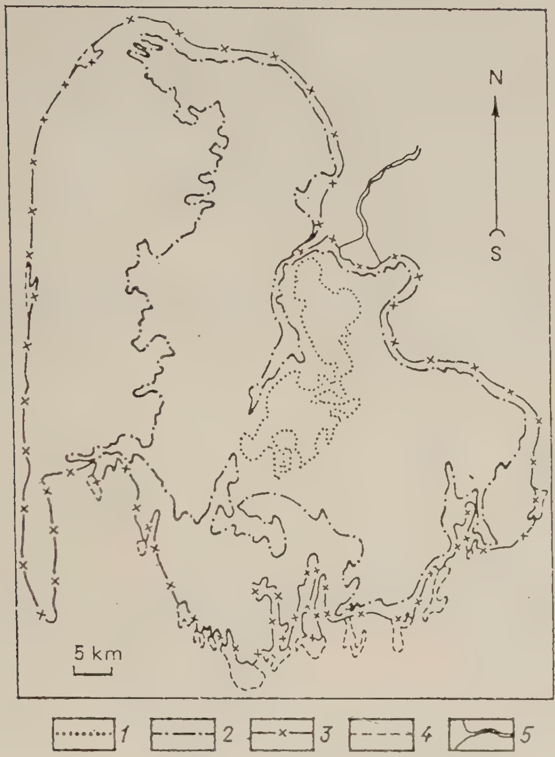
Methods/Equipment

Black-and-white space imagery was obtained for the period 1973-1985, and it was used to reveal changes in the appearance of the lake and to assess its current condition. A map of changes in the lake was compiled from the results of image analysis (Figure 7.9), which provided a graphic illustration of the expanding reservoir. The position of the lake's shoreline, as determined from a 1965 topographic survey, was used in the map construction. The volumetric characteristics of the lake were determined from the comparison of its aerial characteristics with observations on the depth of the water in the lake.

Results/Conclusions

Analysis of the RS imagery provided a temporal picture of the development of the lake. By 1968 the eastern part of the present lake basin was inundated. With the continued inflow into the lake, the water then spread out over an extensive gently sloping area to the east, southeast and west. By 1975 practically all the south-eastern and half of the western part of the basin were flooded - the water area of the lake having increased more than 10-fold relative to 1965. As a result of the continued growth in the volume of incoming irrigation wastewaters, further displacement of the shoreline to the southeast, east and north has occurred since 1975. The greatest changes, however, have occurred in its southern and western parts because of the intensive flooding of a vast plain consisting of an area of saline soils and playa deposits. The water area of the lake during the 10 years from 1975 to 1985 increased by 80% and the water volume by 115% (Table 7.3).

Figure 7.9 Map of the Dynamics of the Water Areas of Sarykamysh Lake



Legend: 1 — 1965
2 — 1975
3 — 1985
4 — forecast for 1988
5 — Dar'yalyk drainage canal.

Table 7.3 Changes in Basic Characteristics of Sarykamysh Lake

Type of Survey	Date	Water Area km^2	Water Volume km^3	Water Level m below m.s.l.
Topographic	1965	159	0.5	-29
Remote Sensing	1975	1762	13.4	-7.6
Remote Sensing	1985	3233	28.3	-1.7
Remote Sensing	1988	3264	30.5	-1.0

The continuing inflow of mineralized irrigation waters and the continued rise in the water table have resulted in major changes in the area adjoining the lake. First, a narrow band of flat and low-lying land adjacent to the shore is damaged by crusts of salt rapidly forming on intensively waterlogged surfaces. Then water reaching the sloping shores dissolves these salts. This process continues sequentially. The salinized land surfaces adjacent to the shore can be detected on space imagery by their light and mottled image.

The rising water table causes small lakes to form in natural depressions. Further flooding results in the growth of these small lakes, which then merge with one another and, subsequently, with the main reservoir.

Discussion/Recommendations

Space imagery has enabled the determination of the direction of the lake's growth and to forecast the position of its shoreline. Analysis of the space imagery for 1975 and 1976 clearly revealed areas that showed waterlogging - these areas were then the first to be flooded. And likewise, analysis of space imagery in 1980 and 1985 again confirmed that areas appearing to be waterlogged always appeared to be flooded on later images. Since this flooding is likely to continue, i.e. because there are no plans to halt the irrigation processes, then it is now possible to draw accurate maps which look at the future incremental growth of Sarykamysh Lake. The modelling of this process would clearly be an example of a useful study which could be greatly and efficiently expedited if performed as a GIS exercise.

Since the author claims that the lake "at present functions only as an enormous evaporation pan" and "is used only for catching fish" (p.77), then it is clear that, given the huge size of the lake, RS has been incremental in revealing the growing potential of a fisheries resource.

Study 6

TITLE: "Mapping Potential Effluent Pathways in the Long Point Region of Lake Erie from Landsat Imagery"

AUTHORS: LeDrew, E.F. and Franklin S.E.

PUBLICATION and DATE: *J. of Coastal Research*; Vol.3, No.2. 1987.

Introduction/Objectives

We have selected this study because it shows the possibility of mapping liquid effluent dispersions in a large lake using RS imagery - clearly the ability to monitor this sort of movement could be of interest to both aquaculture and inland fisheries.

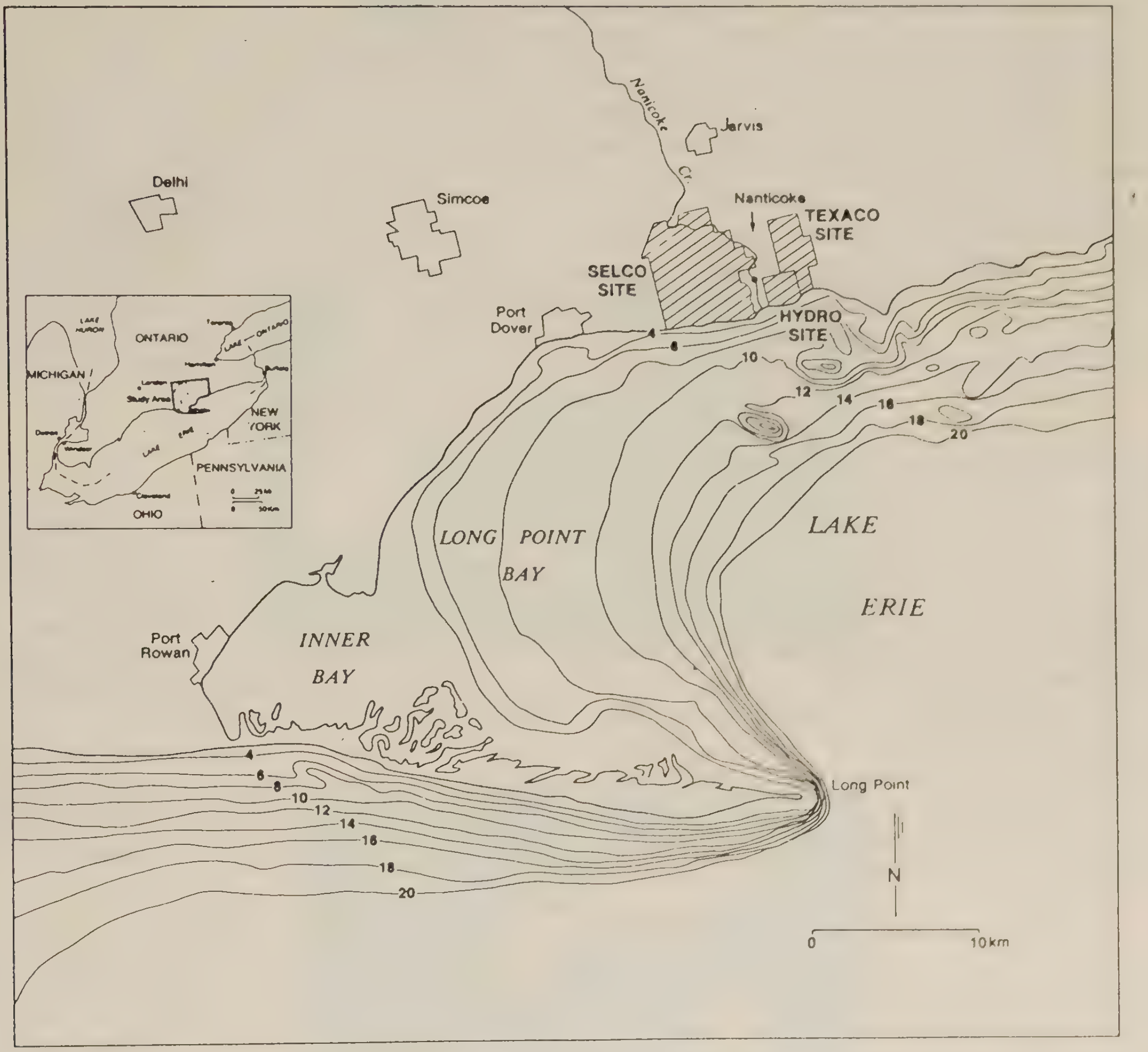
Industry has been attracted to the Long Point Bay area on the north shore of Lake Erie in Canada because of greenfield site availability, inexpensive water transport and nearby markets. Figure 7.10 locates the area and gives an indication of bathemetry. As the industry and its supporting urban structure expands, it can be anticipated that effluent discharges to the lake will increase. The study seeks to find out what the ultimate long distance destinations of the effluents are. There are suggestions that the currents within the Long Point Bay area may form a closed gyre (spiral) so that accumulations of polluted sediments accrue in the eye. However, this is uncertain. What is certain is that the southern shores of the bay are very sensitive ecologically.

In this study Landsat imagery of the Long Point region is examined to identify the geometry of the surface currents for several dates, and for several different wind directions, to determine whether there is a gyre or alternative current configuration and what its spatial characteristics are.

Methods/Equipment.

The authors commence this section with a brief look at the problem of which spectral bands give the best indicator of sediment movements in water. There is conflicting evidence on this which results from the large number of variables concerned, e.g. size of sediment particles, amount of sediment, time of image, other pollutants present, depth of water, etc. Band 4 is certainly able to achieve greater depth penetration (up to 20 m) but this is of little value in sediment laden waters. There is a lack of historical records which relate measured sediment densities to particular Landsat images. Consequently, the authors map sediment tendrils as proxy indicators of the current directions on the presumption of mass transport down the density gradient, i.e. even though a single image is a static representation and does not reveal the dynamic nature of a surface.

Figure 7.10 Development Areas and Bathemetry Around Long Point Bay, Lake Erie


Nanticoke Cr.
Jarvis
Delhi
Simcoe
Nanticoke
TEXACO SITE
SELCO SITE
Port Dover
HYDRO SITE
4
6
10
12
14
16
18
20
LAKE HURON
ONTARIO
Toronto
LAKE ONTARIO
Hamilton
Buffalo
MICHIGAN
London
Study Area
NEW YORK
Detroit
Windsor
LAKE ERIE
PENNSYLVANIA
Cleveland
OHIO
0 25 Mi
0 50 Km
LONG POINT BAY
LAKE ERIE
Port Rowan
INNER BAY
Long Point
4
6
8
10
12
14
16
18
20
N
0
10 km

Sediment patterns for eight dates were mapped, having selected fiche records of Landsat imagery to identify images with sufficient gradation of tone within Long Point Bay to map sediment tendrils. For each date the prevailing wind pattern in the area was determined from a nearby ground station in order to establish a "regional air flow", the prevailing directions and an average speed.

Digital image processing techniques were applied, plus some necessary image enhancement, and one image was geometrically corrected to UTM map co-ordinates. Other images were registered to this. The most useful image enhancement technique, for the purpose of delineation of the fine structure of the sediment tendrils, was a histogram stretch of Band 4. In this procedure the original limited range of reflectance values was redistributed over the entire tonal range by assigning equal memberships to each possible class of reflectance values. Band 7, which has negligible reflectance from water, was used to identify the shoreline. To quantitatively map the sediment contours, a density slice of Band 4 was used. This breaks the reflectance signal into discrete classes that may be colour coded in a map. The density slice was implemented by applying a parallelepiped classification to Bands 4 and 7 so that information in Band 7 could be used to mask the land surface. The sediment contours were mapped from the density sliced digital image, and the arrows depicting the authors interpretation of current direction are based upon evaluation of the contours and the histogram enhancement of Band 4. Black and white renditions of the original colour enhancements and classifications were provided for each case. Figure 7.11 gives an example of one of eight selected images studied.

Results/Conclusions

The authors then describe in some detail their interpretation of four of the eight enhanced Landsat images. We need only summarize the details for Figure 7.11. On July 6, 1974 (incorrectly dated as July 7, 1979 in the journal) there were surface winds, averaging 4.8 km/hr, blowing from the S.W. On the previous day the mean wind was from the N.W., but it was from the S.W. from 1 to 4 July. East of Nanticoke, there was an east component to the littoral drift, while to the west it was westwards. Sediment concentrations were higher in the Nanticoke region than to the west and south of Long Point Bay, which is indicative of higher erosion rates in this region. To the south of Long Point, the littoral transport was strongly to the east until the coast curves north. At this point the current became detached from the shore, meandered southwards and then evolved into a pronounced anti-clockwise gyre. It appears that the current had an inherent instability that became evident in a vortex after it left the confines of the shallows.

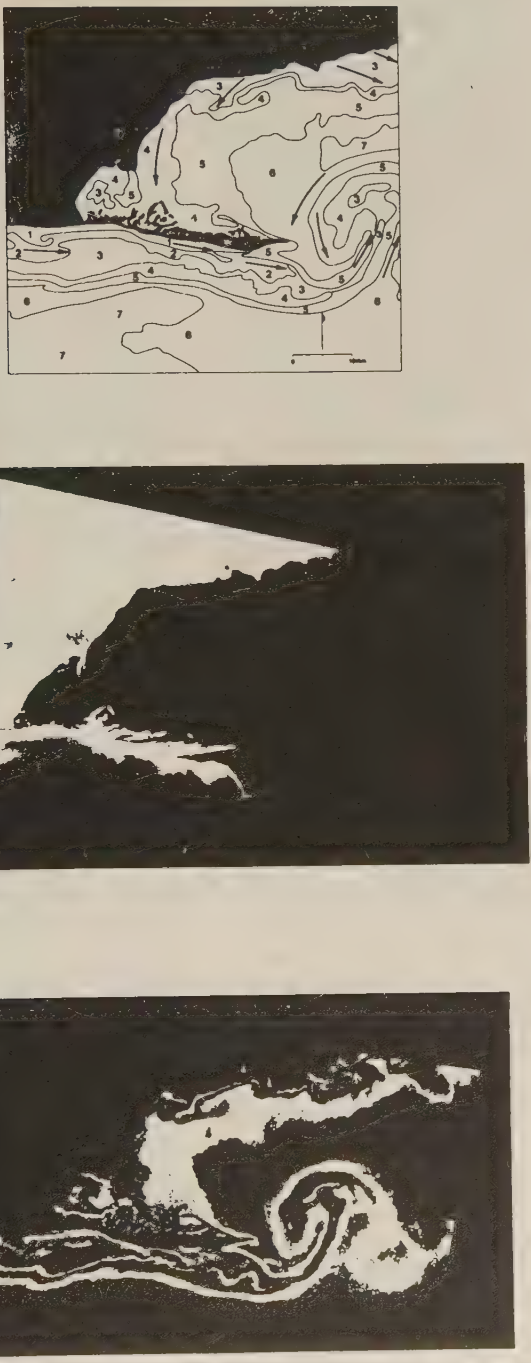
Discussion/Recommendations

There are several pronounced features which can be inferred from this study. The easterly drift along the southern shore of the Long Point Spit is a major feature in most weather patterns. Towards the end of the spit, where it curves northwards, the drift becomes detached before starting the large anti-clockwise gyre to the east and north of the spit. Only at times when the wind has a northerly component is this pattern broken. This easterly drift along the spit is consistent with a "coastal jet" type current. It is strong, able to carry large quantities of sediment, is probably causing erosion, and more importantly to the aim of the study, is able to efficiently carry pollutants. Any industrial development to the west of the spit would mean that any effluents would be transported eastwards and, having passed the spit, they might curve around northwards and finally settle in the calmer waters of Long Point Bay. The general westwards movement of sediments along the north of Long Point Bay appears to be a component of the gyre within the bay.

It appears that the urban/industrial complex sited on the north shore of the bay (see Figure 7.10) is critically located as far as effluent dispersal is concerned. Had it been located a few miles further west, then most of the effluent would have been dispersed to the Long Point Bay gyre - and probably finish up polluting much of the bay as well as critically affecting the local coastal ecology. As it is, a good proportion of the effluent is likely to get caught in an easterly or off-shore water movement pattern and it is probably distributed into the eastern basin of Lake Erie.

Analysis of local plume dispersion by RS imagery can only form part of a study of the impact of potential pollution. The cumulative effect of several developments and the associated urban infrastructure in the region must also be considered. Additionally, it would be advisable to monitor sediment dispersal patterns over a much wider region. Long-term RS imaging should prove the ideal means of doing this and of eventually showing the final destination of effluent concentrations.

Figure 7.11 Density Sliced Image, Black and White Image and Interpretation of Sediment Plumes in Long Point Bay for July 6, 1974



Study 7

TITLE: "A Geographical Information System for Catfish Farming Development"

AUTHORS: Kapetsky, J.M., Hill, J.M. and Worthy, L.Dorsey

PUBLICATION and DATE: *Aquaculture*. Vol.68. 1988. pp311-320.

Introduction/Objectives

The authors recognize that there is a need to increase protein supplies world-wide using various "aquafarming" techniques but, until recently, very little attention had been given to evaluating the water, land and human resources necessary, or to look at various environmental and economic constraints to further development. Planning for suitable locations for increasing inland fish production is mostly carried out at a "middle" governmental level, e.g. by districts, county or provinces, though it might be local fisheries officers who would advise on specific sites for production, and who would need information to help with this.

This study is confined to Franklin parish (county) in Louisiana, U.S.A., and the species is Channel Catfish. There were more than 1 000 ha of catfish ponds here in 1986 producing nearly 1 000 tons of intensively farmed fish from 40 different farms. Franklin is the leading parish in Louisiana for catfish production. Catfish farming in the U.S.A. is highly competitive and careful attention to siting can result in significant economic advantages. The primary objective of the study was to show how a GIS could be used to locate and inventory areas suitable for aquaculture at the county level, and to test the results against the actual locations of catfish farms.

Methods/Equipment

The GIS assessment was linked to the Parish, rather than to a geomorphological unit, because most data is reported by administrative unit and because development decisions are likewise implemented.

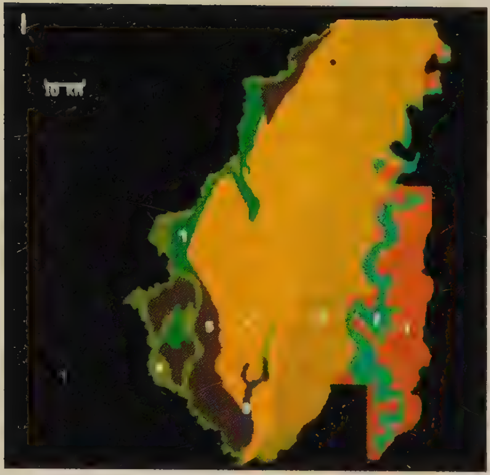
Since almost all of Franklin parish is flat (elevational range = 11 to 42 meters) then potentially catfish ponds could be developed almost anywhere. The main criteria for development used by the authors was on the physical characteristics of soils, i.e. in terms of their suitability for:

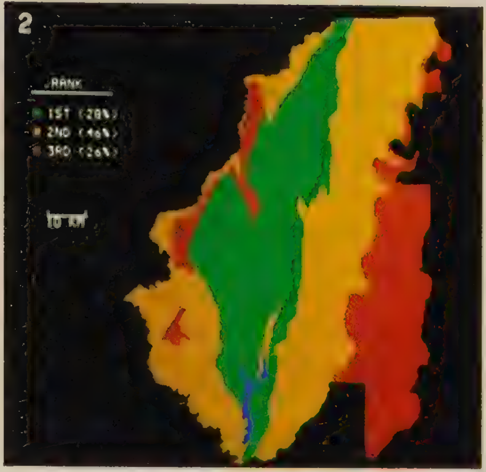
i) Pond construction - permeability as it affects seepage.
ii) Levee construction.
iii) Commercial buildings - providing suitable foundations for.
iv) Local roads - traffic supporting capacity.
v) Equipment - restricting use of heavy equipment.

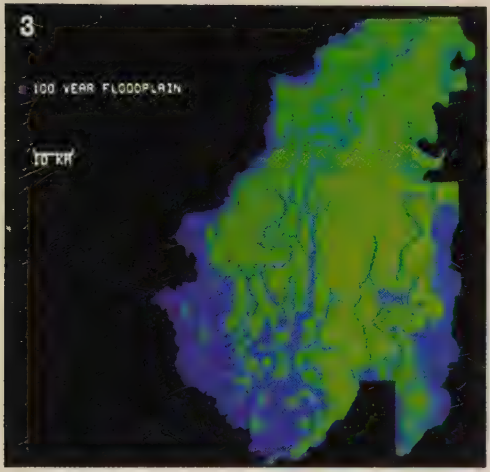
Detailed information was available for all soils in Franklin parish. This categorized them into 7 general, and 28 more detailed, soil map units (Figure 7.12 - 1). It was possible to "rate" all the soil categories, for each of the five land uses given above, so as to arrive at a "pond suitability score" for the whole parish (Figure 7.12 - 2).

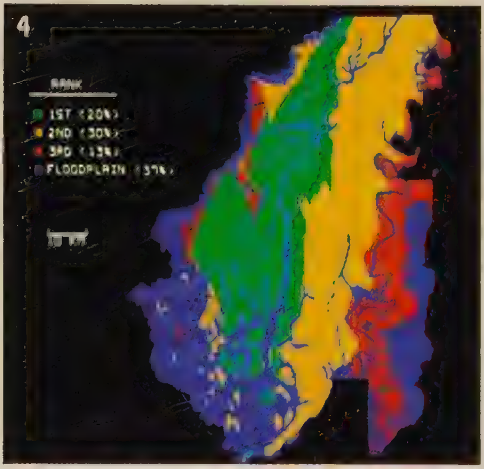
A second location criterion used was susceptibility to flooding, and use was made of a map showing all areas with more than a 1% probability of flooding each year (100-year floodplain map) (Figure 7.12 3). A map showing the location of the existing catfish farms was also drawn up.

Figure 7.12 Maps of Franklin Parish, Louisiana, Showing Suitability for Catfish Farms




2
RANK
1ST (28%)
2ND (46%)
3RD (26%)
10 KM


3
100 YEAR FLOODPLAIN
10 KM


4
RANK
1ST (20%)
2ND (30%)
3RD (13%)
FLOODPLAIN (37%)
10 KM

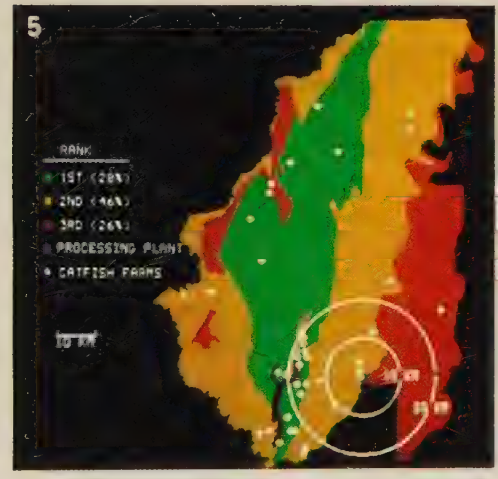

5
RANK
1ST (28%)
2ND (46%)
3RD (26%)
PROCESSING PLANT
CATFISH FARMS
10 KM

Fig. 1. The general soil map units of Franklin Parish: (1) Sharkey-Tensas, (2) Dundee, (3) Calhoun-Calloway-Loring, (4) Gilbert-Gigger-Egypt, (5) Necessity-Foley-Deerford, (6) Forestdale-Sharkey, and (7) Dexter-Liddleville-Necessity. Turkey Creek Lake is 8.

Fig. 2. Suitabilities of soils for catfish farming development.

Fig. 3. The area of Franklin Parish within the 100-year floodplain.

Fig. 4. Suitabilities of soils for catfish farming which are outside of the 100-year floodplain.

Fig. 5. Suitabilities of soils for catfish farming compared with the locations of existing catfish farms. Proximity to a processing plant is also shown.

Table 7.4 Characteristics of Franklin Parish Soils Relative to Catfish Farming Development

General map unit	Detailed map units (% of area)	Area of parish (%)	Numerical ratings						Final relative rating	Observations
			Ponds	Levees	Roads	Equip-ment	Build-ings	Overall numerical rating		
1	Sharkey-Tensas (80-14)	16	2.9	1	1	1	1	6.9	Poor	Wetness limits most uses
2	Dundee (90)	5	2	1	1	2	2	8	Poor	Wet; permeable
3	Calhoun-Calloway-Loring (36-27-24)	33	2.4	1.3	1	1.9	1.3	7.8	Fair	Level to gently undulating
4	Gilbert-Gigger-Egypt (46-30-12)	29	3	1	1.3	1.8	1.3	8.4	Good	Level to gently undulating
5	Necessity-Foley-Deerford (43-30-25)	8	3	1.4	1	1.7	1	8.1	Fair	Level to gently undulating
6	Forestdale-Sharkey (52-46)	6	3	1	1	1	1	7	Fair	Fo. higher, less wet than Sh.
7	Dexter-Liddieville-Necessity (68-20-10)	3	1.4	1.1	1.2	2.9	2.8	9.4	Poor	Permeable; high relief

The soil map and the 100-year floodplain map were digitized. This information, along with the necessary attributes and the fish farm location map, were input to a computer at the Louisiana State University Remote Sensing and Image Processing Laboratory - an ELAS GIS software package was used for data processing.

Results/Conclusions

Table 7.4 gives the numerical ratings and final relative ratings for the 7 general soil units, and on Figure 7.12 - (4) the areas are ranked in order of suitability. It can be seen that the final relative ratings do not necessarily concur with the total soil suitability ratings because an assessment of other criteria has been introduced. For example, "general map unit" 7 (Dexter-Liddleville-Necessity) was rated first for soils, but its overall relief was disadvantageous to pond construction resulting in a final "poor" rating. Map unit 4 was considered to be the overall best area for pond construction on account of its suitable soils, its relatively level land, very little of which was flood prone. It is interesting to note from Figure 7.12 - (5) that about half of the existing catfish farms are located in areas indicated by the GIS as being most suitable. Only two of the 40 farms are located in the least suitable areas.

Discussion/Recommendations

Though the results show that a GIS can be used to locate, map and inventory areas which are suitable for catfish pond development, there are many ways in which it could be improved. Other location criteria would certainly be worthy of addition. These include:

i) Ground water depth.
ii) Water quality.
iii) Soil chemical characteristics - as they affect water productivity and quality.
iv) Distance from feed suppliers and fish processing plants - as they affect transport costs.
v) Spatial development cost variations, e.g. cost penalties for siting within the 100 year floodplain area.
vi) A slope map could have been incorporated to eliminate the subjectivity in assessing the final relative ratings shown in Table 7.4.

The study shows that an effective GIS for aquaculture planning need not be complex or expensive. Once the data bases have been captured, updating is easy and the data can be manipulated to achieve various simulations, e.g. what effect would raising levee bank heights have on diminution of flood prone areas?

Study 8

TITLE: "Where Should Trout Farms be in Britain?"

AUTHOR: Meaden, G.J.

PUBLICATION and DATE: *Fish Farmer;* Vol.10, No.2. 1987.

Introduction/Objectives

Trout farming in Britain has undergone considerable expansion over the past decade. This has been in response to rising demands, to the greatly increased cost of wild-catch fish, to a diffusion of knowledge about trout farming potential and to the needs of farmers to diversify in diffusion of knowledge about trout farming potential and to the needs of farmers to diversify in times of food stockpiles and insecure farm incomes. Where should prospective trout farmers be looking to find commercially viable situations for farming in England and Wales? The basic objective of this study was to outline a methodology which could be used to answer this question. It was an exercise in applied spatial analysis, i.e. the author was concerned that so many business enterprises had been unsuccessful simply because they were poorly located, and the importance of the location decision to business success has been grossly underestimated.

Methods/Equipment

To determine location suitability it was first necessary to establish those factors of production (production functions) which controlled trout farming, i.e. mostly physical and economic factors. From a large number of factors identified, those which showed spatial variability were then isolated (see Table 7.5).

Table 7.5 Spatially Variable Production Functions Associated with Trout Farming in England and Wales

i) Water quality.
ii) Water temperatures.
iii) Water quantity.
iv) Availability of underground water.
v) Relief.
vi) Precipitation.
vii) Nearness to the source of the waterway.
viii) Agglomeration.
ix) Land costs.
x) Access to road transport.
xi) Distance from catering markets.
xii) Distance from wholesale markets.
xiii) Distance from restocking markets.
xiv) Distance from competing trout farmers.

The methods used to map and compare the suitability of different areas for trout farming involved eight stages:

i) For mapping purposes the area of England and Wales was divided into a grid of 10 km^2 cells, i.e. a total of 1 706 cells.

ii) A map was produced for each of the production functions listed in Table 7.5, showing its distribution throughout England and Wales.

iii) A "score", ranging from 0 to 10, was allocated to each cell according to its ability to provide for each production function. Those which had no monetary value (the physical functions) could then be "costed" on a similar scale to economic inputs.

iv) All trout farmers in England and Wales were sent a questionnaire which asked them to "weight", on a scale of 0 to 6, the relative importance of each function in helping them to achieve commercial viability.

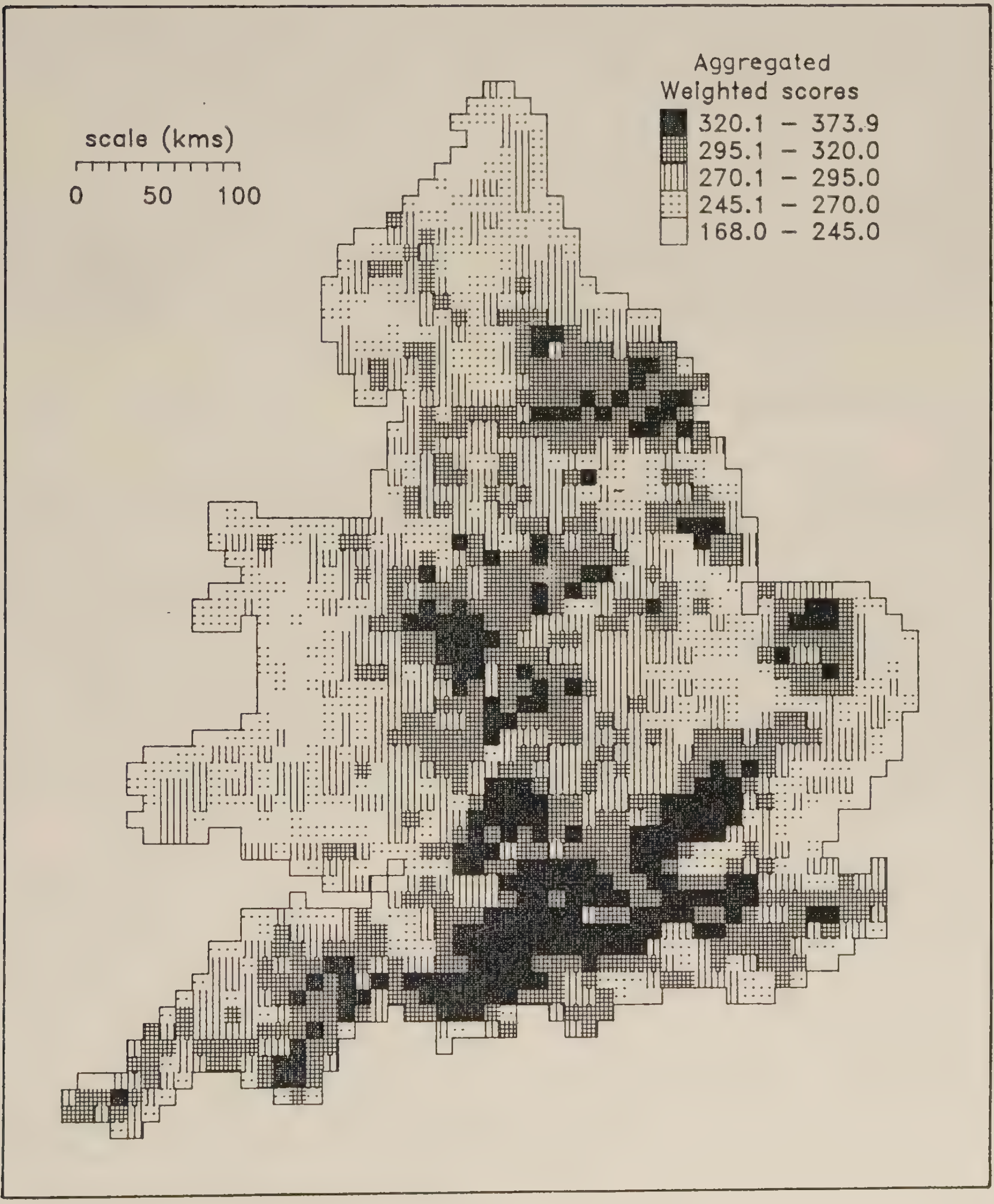
v) A "mean weighting" could then be established for each production function, showing its relative importance to trout farming.

vi) The "mean weighting" given to a function was multiplied by the "score" allocated to that function (in iii above) for each cell to achieve a "weighted production function score".

vii) The 14 "weighted production function scores" were aggregated to produce an "aggregated weighted score" for each cell. These scores could be ranked to show the order of suitability of cells for trout farming potential.

viii) The "aggregated weighted scores" formed the basis of a final map (Figure 7.13) showing areas of relative suitability for trout farms by 10 km^2 cells.

Figure 7.13 Areas of Suitability for Trout Farms, by 10 km^2 cells


scale (kms)
0
50
100
Aggregated Weighted scores
320.1 - 373.9
295.1 - 320.0
270.1 - 295.0
245.1 - 270.0
168.0 - 245.0

The simple mathematical functions (multiplication and aggregating) were performed on a VAX minicomputer and mapping was done using a GIMMS cartographic software package, though this manipulation and plotting could now be performed using less sophisticated devices. The author then lists a number of simplifying assumptions which are inevitable in any process modelling the real world.

Results/Conclusions

Figure 7.13 clearly highlights the suitability of central southern England for trout farming, with its favoured areas of chalk or limestone hills providing high quality water, of a uniform temperature and having a consistent flow rate, i.e. little variability. These areas also have good access to road transport, high agglomeration potential, reasonable land costs and they are not too far from the various market outlets. Other major areas showing potential are the Yorkshire, Norfolk and Lincolnshire Wolds and an area in the West Midlands.

It is of interest to note that some of the areas which had traditionally been seen as being good trout farming areas, in fact scored very poorly. These included upland areas such as much of Wales, the Lake District and the Pennines. In these areas water temperatures and flow rate variability are poor, climatic conditions and relief are adverse, though the major problem is the distance from most markets. The author also explains why other areas are unsuitable.

It is worth testing the methodology by seeing if existing trout farms are located in areas which were shown to be suitable. An analysis revealed that 32% of all farms were located in cells which were ranked as being in the top 10% in their suitability for trout farming. From the data gathered, it was also possible to work out those parts of England and Wales which were either over- or under-represented as far as the number of trout farms was concerned - information which could be very valuable to prospective fish farmers.

Discussion/Recommendations

The analysis was very detailed and data capture was a lengthy exercise which relied on the availability of a large amount of secondary data. Once captured, however, the necessary up-dating could be simply carried out and the data bases could be modified as either more refined data were found or if the exercise was to be carried out at a different scale. The study also showed that different results could be produced if, at the "weighting" stage (described in (v) above), only questionnaire responses from selected groups of trout farmers were selected, e.g. farmers who were producing for the restocking market or farmers who were utilizing a particular type of production system (perhaps using polythene tanks). This would produce different "mean weightings" as different groups of farmers might see different production functions as being important to their type, or sector, of trout farming. Clearly different final maps would then result. Indeed, it would not be necessary to use groups of fish farmers at all, i.e. any potential or actual trout farmer could use weightings according to his perceptions of their relative importance.

Study 9

TITLE: "Microcomputer Spreadsheets for the Implementation of Geographic Information Systems in Aquaculture. A Case Study of Carp in Pakistan"

AUTHORS: Ali, C.Q., Ross, L.G. and Beveridge, M.C.M.

PUBLICATION and DATE: Accepted for publication in *Aquaculture*. (1990)

Introduction/Objectives

Most GIS studies have used commercial GIS programs or packages. This study was chosen because it shows a method of attaining limited GIS functionality through the use of a more readily obtainable, and usually more familiar, spreadsheet package. The study shows how microcomputer spreadsheets can aid in the location decision, using carp culture in Pakistan as an example.

The authors state that in many cases access to the detailed graphical and analytical facilities of full-scale GIS programs is not possible and the necessary investment funding would not be there. However, since microcomputers are now widely available, as are various mathematical spreadsheets, then this offers an easy alternative. Spreadsheets are simply a two-dimensional array of cells which can accept any data, i.e. they can substitute as an x and y co-ordinate system of geographical references. Consequently, they could be very suitable for simple GIS work, provided that the source data can be arranged in raster format.

Methods/Equipment

A 1:2 000 000 scale relief map of Pakistan was used to trace an overlay which divided the country into 172 cells each representing a 75km x 75km area. The following list of factors was chosen as selection criteria relevant to the development and location of carp culture:

i) Air temperature.
ii) Surface water availability.
iii) Soil type.
iv) Precipitation.
v) Availability of underground water.
vi) Slope.
vii) Availability of fish seed.
viii) Distance from wholesale markets.
ix) Access to road transportation.

Most data for each of these criteria was obtained from a series of maps published by the Pakistan government, though in some cases additional data was obtained from specific government ministries. The data for each criterion, in each grid cell, was scored on a scale of 1 to 5, with 5 representing the highest suitability of the parameter and 1 the lowest. The scored data was then entered into the spreadsheet package on a BBC-B microcomputer in a blocked layout which spatially represented the country. After the scoring of cells, a weighting was given to each parameter, according to how important it was seen to be. Weightings varied between 0 and 1. Scores were then multiplied by their relevant weightings and aggregated and the overall score obtained was thus a rating of the suitability of that cell for carp culture. The calculated sheet was printed on a wide carriage printer and, by using the condensed character set, a large grid could be printed (Figure 7.14).

Figure 7.14 Scored Cells Showing Suitability for Carp Culture in Pakistan

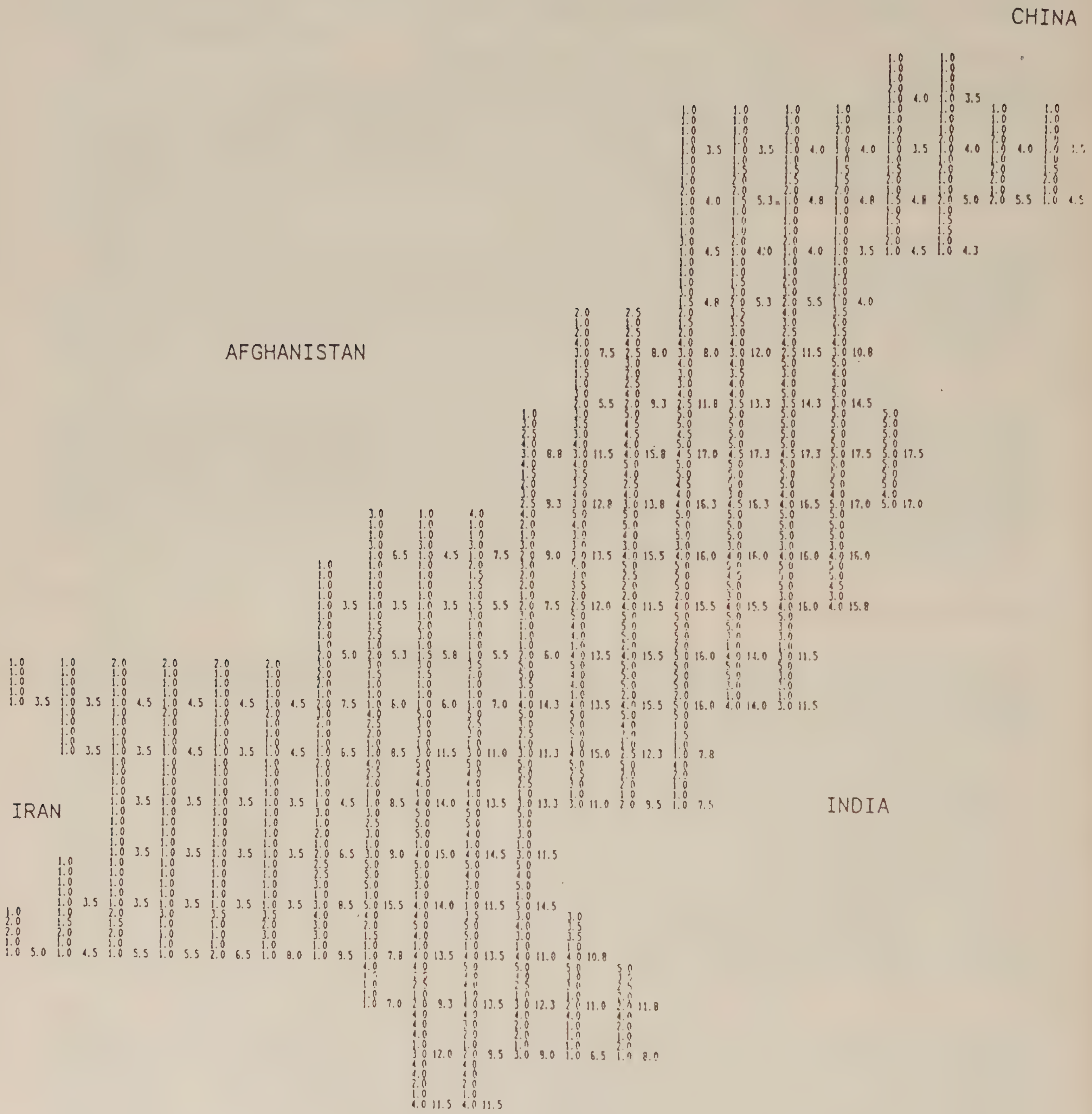
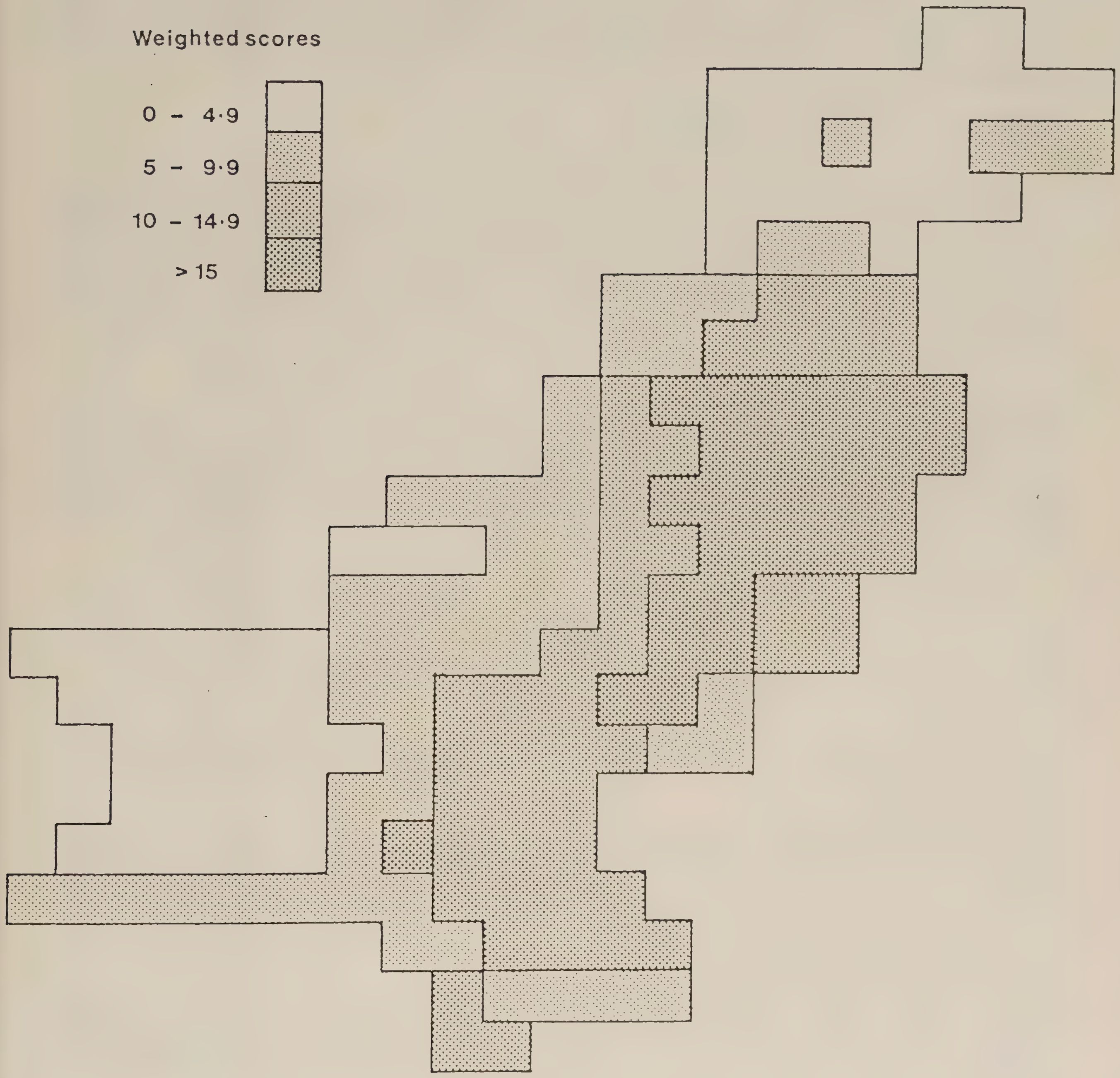

CHINA
AFGHANISTAN
IRAN
INDIA

Figure 7.15 **Graphic Representation of Cell Scores Showing Suitability for Carp Culture in Pakistan**


Weighted scores
0 - 4·9
5 - 9·9
10 - 14·9
> 15

Results/Conclusions

The simplicity of this system is clearly seen, as is the ability to manipulate the scored spatial data, i.e. where up-dating is necessary or in order to give greater weighting to certain parameters. The overall scores can be represented graphically using shaded blocks - Figure 7.15 is the graphic representation of Figure 7.14. It appears that the most suitable areas for carp rearing are in central-eastern Pakistan where many tributaries of the River Indus converge across a wide flood plain.

Discussion/Recommendations

Within the limitations set by the data, the GIS gave quite acceptable results. Data extraction and entry was relatively time-consuming although this must be expected for any system. Once data had been entered it was a very simple task to manipulate it as required and to print the results. The system very much depends on the availability and the accuracy of the initial data, plus the ability of the user to objectively score and weight it. This approach has an advantage over fully automatic data entry, e.g. raster scanned data, in that all data points have been evaluated by the operator.

The resident memory of 32K in the computer allowed entry of 5 parameters in 172 blocks and the calculation of a single result per block. As microcomputer memory increases, these restrictions would ease. The authors suggest a number of further refinements which could be incorporated to improve this microcomputer approach, e.g. using linked worksheets, one for each parameter, with scores being calculated in a further worksheet, or a spreadsheet-based GIS could have program user interfaces written to provide graphical output.

Study 10

TITLE: "A Geographical Information System for Aquaculture Development in Johor State"

AUTHOR: Kapetsky, J.M.

PUBLICATION and DATE: FAO: Technical Cooperation Programme. FI:TCP/MAL/6754. 1989.

Introduction/Objectives

This is a further major study on the application of GIS to aquaculture. As such it will be impossible to present a summary of the whole report as a complete case study. What we present is a brief synopsis of the study's aims and methods, as gained from its summary, and then a more detailed look at its recommendations.

The study is a report on an FAO Technical Cooperation Programme intended to train Malaysian Dept. of Fisheries personnel in using GIS as a tool for planning and aquacultural development. Incorporated within this training was the setting up of an aquacultural GIS for Johor State, and it is this that the author concentrates on. The main objective was to locate further opportunities for shrimp farming in ponds and culture of fish in cages generally in the Johor Strait area. Location criteria were established relative to the known demands of the industry - these are summarized for both farming and cage culture in Table 7.6. The data for each of these location criteria was assembled from a variety of sources which the study gives. The data were entered, manipulated and analyzed using commercially available GIS. The hardware and software components of this are shown in Table 7.7.

Table 7.6 Main Criteria and Components Used in the GIS to Identify Opportunities for Shrimp Farming and for Cage Culture of Fish

	Shrimp Farming	Cage Culture
INFRASTRUCTURE: Primary roads Secondary Roads Cities and towns	X	X
WATER QUALITY TIME SERIES: Ammoniacal nitrogen Biological oxygen demand pH	X	X
WATER QUALITY AND LAND USES: District land uses: Agriculture Urban Mining District boundaries Drainage basin boundaries	X	X
ANNUAL PRECIPITATION: Rainfall isohyets	X	-
SOILS: Hydrogen ion concentration Texture	X	-
SHRIMP FARM SITES:	X	-
FLOATING CAGE SITES:	-	X
BATHYMETRY: Mudbanks 2, 5, 10 and 20 meter contours	-	X
SHELTER: From the north within 2 km of coast	-	X
CURRENT SPEED:	-	X
SPOT DIGITAL DATA: 3 scenes covering part of Johor State	X	X

Table 7.7 Hardware and Software Components Used in the Johor Aquaculture GIS

IBM PC/AT host computer with:

- 640K memory
- 1.2 MB floppy disk drive
- 30 MB hard disk

Mitsubishi 512 x 512 image display
Tektronics 4696 colour printer
Epson EX-1000 line printer
Cipher tape drive
Calcomp 9100 digitizing board

ERDAS Core, GIS and image processing packages
and modules -
Version 7.2

Results/Conclusions.

Shrimp Farming Opportunities. Although about 193 000 ha of coastal Johor is within easy reach of a water source for shrimp farming, only about 6% of this area includes soils which rated "fair" or suitable in texture and pH. Most of these better soils are in the south and south-east coasts. Field verification data called attention to the costs of siting on acid and poor texture soils. In terms of water quality, as inferred from land uses and measurements of pH, BOD and NH-3, the west portion of the south coast and the vicinity of Johor Baharu are areas where development should proceed with caution (Figure 7.16). Salinities and pH were favourable nearly everywhere.

Cage Culture. In relation to the main criteria (Table 7.6) the west coast offers few opportunities. Much of the south-west coast is too shallow, except in the mouth of the Sg. Pulai where cage installations could interfere with navigation. All of the Johor Strait area is well sheltered although only 12% of it has depths rated as good or fair. Water quality in the west Straits, and in the vicinity of Johor Baharu, is less well suited to cage culture than elsewhere. Current speeds are a problem in many areas. Apart from the lees of some islands, there is little shelter on the east coast for cage culture. Further work needs to be done on plotting bathemetry inside some of the apparently favourable estuaries. In addition to the criteria originally selected, agglomeration and security should be taken into consideration.

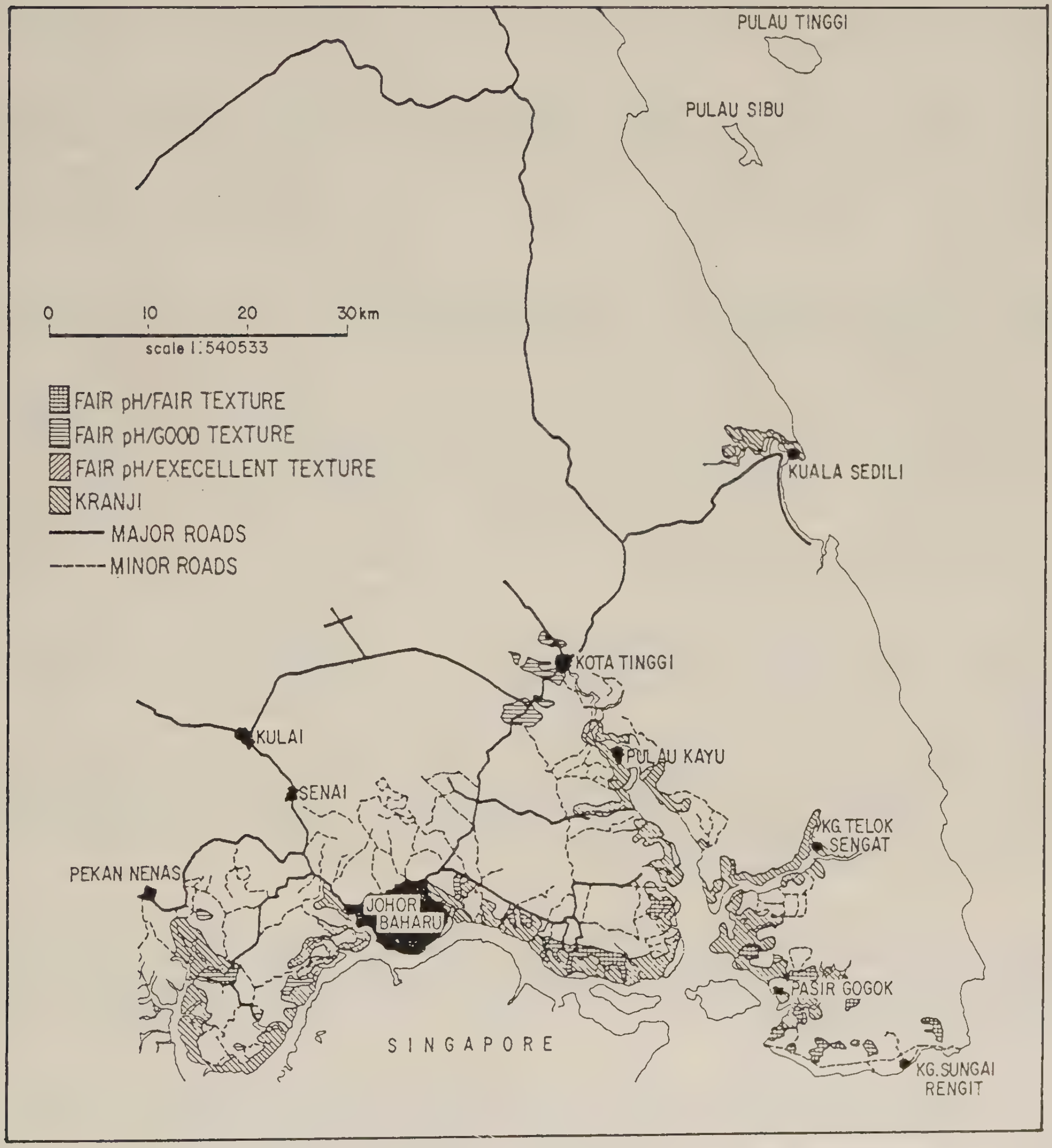
Discussion/Recommendations.

These recommendations deal with both how the Johor State GIS information base should be expanded in technical and operational terms, and the requirements for further use of the GIS approach for land and water use planning in other states. We will use the sub-headings as reported by the author.

A. *Information from existing aquaculture facilities.* The sitings specification experience gained from existing aquaculture operations should be compiled from site visits and interviews before the GIS analyses begin, i.e. in order to enable better site selection criteria to be established before the commencement of each study.

B. *Remote sensing*. Satellite (or airborne MSS) data should be obtained in areas where large-scale maps are outdated. RS data can also assess site suitability, land cover and land uses, which can be used to estimate site preparation costs and site purchase costs. Land uses adjacent to the site will indicate dangers from pesticide pollution and other possible water quality problems. By using RS to take an inventory of existing shrimp farms, the overall management can be controlled and agglomeration advantages could be established.

Figure 7.16 Map Produced by the GIS Showing Main Soils and Roads in S.E. Johor State


PULAU TINGGI
PULAU SIBU
0 10 20 30km
scale 1:540533
FAIR pH/FAIR TEXTURE
FAIR pH/GOOD TEXTURE
FAIR pH/EXECELLENT TEXTURE
KRANJI
MAJOR ROADS
MINOR ROADS
KUALA SEDILI
KOTA TINGGI
KULAI
SENAI
PULAU KAYU
KG. TELOK SENGAT
PEKAN NENAS
JOHOR BAHARU
PASIR GOGOK
SINGAPORE
KG. SUNGAI RENGIT

Because the use of mangroves and other wetlands for aquaculture is a sensitive issue, mangrove limits need to be carefully defined in the GIS data base. Existing data on the extent of mangrove areas is poor, and RS offers an exceptional opportunity to complete and up-date its existing mapped areas. An additional advantage of using RS imagery is that individual mangrove species can be defined, and aquaculture facilities could be sited among the least productive and least valuable species. Existing satellite data can also be used to assess the limits of sediment plumes. Weather satellite imagery (AVHRR) could be used to identify areas having consistently high primary production. These would be economical as one scene covers the entire peninsula and the cost is only a fraction of that of Landsat and SPOT images. The author suggests that an arrangement might be possible to acquire AVHRR CCTs from the Malaysia Meteorological Service at a reduced cost after they had been used for weather forecasting.

C. *Water quality analyses*. There are marine data sets which contain a variety of water qualitative information useful to coastal aquaculture, and these are suggested. Data on the build up of contaminants in cage-cultured fish could be used to delimit areas where coastal aquaculture should not be developed. A staff member from the pollution unit of the Fish Research Institute should be assigned to a multi-disciplinary team to analyze the raw data which the FRI holds, plus data from other sources. He or she could also help to assess the link between agricultural crop type, pesticide use and the potential effect of this on aquaculture.

D. *Impact of rainfall on pond acidity*. Since the effect of rainfall on pond acidity is quite marked, especially where monthly precipitation is in excess of 400 mm, then at least three years of data should be analyzed to determine the locations having unfavourable rainfall during a month or shorter interval. The results of this rainfall analysis should be entered into the data base.

E. *Additional aquaculture development opportunities*. The data bases already established should be expanded, or differently interpreted, to help other aquacultural opportunities in Johor, e.g. cockle, mussel and oyster culture.

F. *Continuation of the work begun by the project*. Although when the project was conceived it was believed that a general land and water use GIS for the entire peninsula would be a logical follow up to the Johor State aquaculture development GIS, it now appears that, because of the large quantity of varied and detailed information available at state level and because land allocation for aquaculture is a state government function, a state by state approach would best serve Malaysia's needs.

G. *Hardware requirements*. Because of the large amounts of data which need to be processed for aquaculture, land and water use planning, it is recommended that the hard disk capacity of the present system should be expanded to at least 80 MB.

H. *Location of the system*. Experience from the project has shown that a location convenient to information needed to build the data base would result in more efficient use of time and personnel, i.e. in this case the Dept. of Fisheries in Kuala Lumpur. Alternatively, the equipment could be moved from state to state as analyses proceed.

I. *Multidisciplinary team*. A team should be adopted for aquaculture development. This should consist of a biotechnologist, an aquaculture engineer, and an ERDAS operator as full-time members. Part-time members should include an economist, and experts in aquaculture extension, water quality and soils. The author briefly outlines the functions that each of these team members would perform.

J. *Data preparation and analyses*. Completion of the aquaculture plan for all peninsula Malaysia can be streamlined by assigning two people to undertake data collection and preparation for one state while the multidisciplinary team is completing the analyses for another state. The data preparation group should consist of one person who works in the state getting information from state government, district and local government, universities and private aquacultural enterprises, and the other member should know sources of information in and around the central government in Kuala Lumpur. In order to speed up GIS preparation, technicians should be employed in map digitizing. A digitizing board and software installed on another computer would free the main computer and software for full-time GIS analytical work.

K. *Time frame for GIS analyses.* Given that the recommendations were implemented, each state's aquaculture development GIS could be completed in about six weeks, including reporting. As experience is gained, succeeding states could complete more rapidly.

Study 11

TITLE: "Use of Geographical Information Systems in Aquaculture Survey"

AUTHOR: Quintero-Marmel, E.A.M.

PUBLICATION and DATE: M.Sc. thesis. - Dept. of Aquaculture and Fisheries Management, University of Stirling, Scotland. June, 1990.

Introduction/Objectives

Although aquaculture is one of the fastest growing food production industries, growth has been accompanied by many business failures and these have helped give aquaculture its image of a risky enterprise. In order to alleviate business failure careful planning is essential. This must be based upon adequate and accurate data and it must utilize methods and resources which are affordable and simple to manage. Traditionally, land resource assessment for primary activities has relied upon the visual assessment of "hand-made" maps. An objective of this study was to show that GIS can now provide a rational and easy way to fulfil these requirements, especially in view of the rapid developments of low cost software and hardware.

Since the handling of geographic data is vital to both land resource evaluation and to the successful functioning of a GIS, then the author usefully delineates many of the basic aspects of spatial data. The major operational features of GIS are also explained, as are examples of GIS in land resource evaluation and more specifically in aquaculture. The author then systematically reviews all the major determinants in site selection. These vary from a look at the variety of objectives which might be pursued; a look at the technology which can be applied to site selection; a look at species selection; at various practical approaches to site selection; at the range of economic resource inputs necessary; at the socio-political and legal aspects and finally a look at all the physical and environmental criteria which may be important to the success of aquaculture. From these general site selection considerations the author moves on to delimiting those factors which should be examined in evaluating any particular site.

In this study a PC-based GIS was used to assess the potential for salmonid sea cage culture in Camas Bruaich Bay on the west coast of Scotland. The GIS software was "OSU-MAP-for-the-PC", a raster-based package developed by the Ohio State University in the U.S. Data on various parameters concerned with shelter and water quality were used to decide the suitability of the bay in terms of size, potential production and location. The study also aimed to assess the cost-effectiveness of using GIS v. manual methods. This entailed keeping accurate budgetry records of costs and the time taken to carry out all operations. Nine aquaculturalists were called upon to carry out the manual assessments.

Methods/Equipment

The collection of data was carried out as follows:

i) A map of the bay, at a scale of 1:2000, was drawn up from data gathered using a theodolite, marking poles and anchored buoys.

ii) A marked pole was placed in the water to check tidal range and thus to extrapolate rates of water exchange in the bay.
iii) An accurate bathymetric contour map of the bay was drawn based upon five transects of the bay using an echo-sounder, suitable adjustments having been made for tide levels.
iv) Current directions and velocities were calculated by using drogues released from buoys and then plotting their routes and timings.
v) Data on prevailing winds were obtained from a nearby meteorological station at Oban.
vi) Fetch distances and directions were calculated from an O.S. map.
vii) A field sampling kit was used to assess salinity, water temperature and dissolved oxygen, readings being taken from reference buoys at various depths during high and low tides.

Data for input to the GIS was collected at two different scales, i.e. 25 x 25 m cells and 10 x 10 m cells, so that a comparison of the resolution and accuracy of the results could be made. Various forms of encoding the data were used as shown in Table 7.8. They all involved assigning a value to each of the grid cells by overlaying a transparent grid base on each of the different data sources shown. For some of the data, i.e. bathymetry, water quality and fetch, it was necessary to interpolate values. Not all of the data considered important were eventually input to the GIS, i.e. algorithms to enable values to be assigned to every cell for wave height and water exchange rates do not exist or cannot easily be drawn up. However, these two factors were generally considered, but not within the GIS.

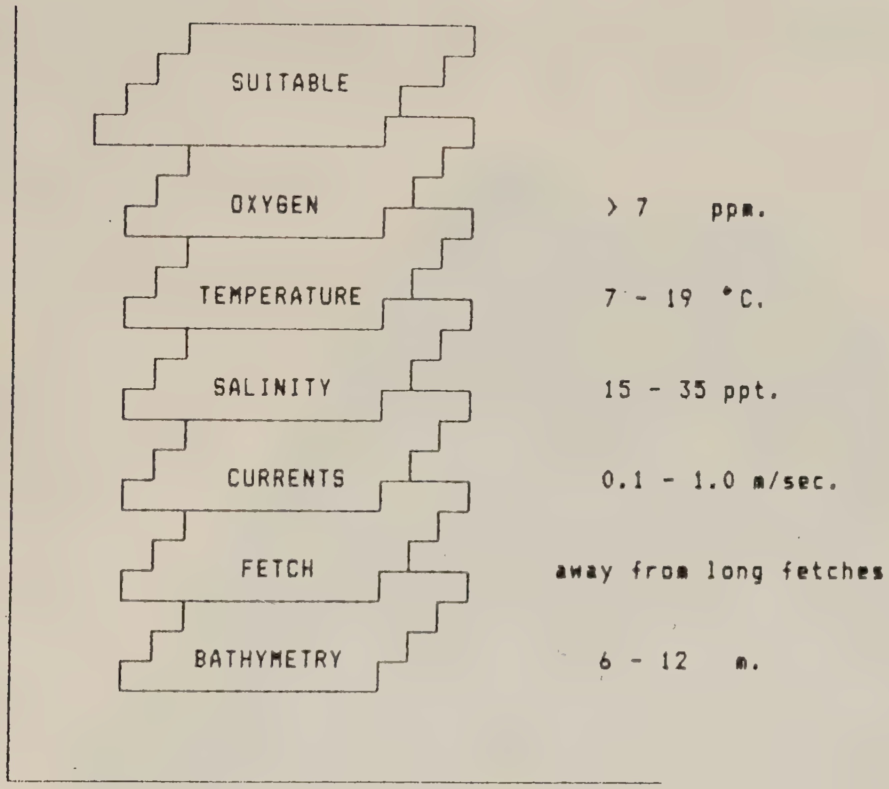
Table 7.8 Data Encoding Method and Data Sources Used

	DATA ENCODING	SOURCE
Bay	Run length codes from an ASCII file.	Theodolite's map.
Bathymetry	Run length codes from an ASCII file.	Bathymetry contour map.
Fetch	Trace code from keyboard.	Reference points from 1:20 000
map.		
Currents	Trace from an ASCII file.	Current map.
Water Quality	Point codes from an ASCII file.	Field data.
Stream	Run length codes from an ASCII file.	Theodolite map.
Roads and Bridge	Trace codes from keyboard.	Reference points from 1:20 000
map.		
Buildings	Point codes from keyboard.	Theodolite map.

Spatial analysis within the GIS consisted of the following steps:

i) Constraints were established for each parameter controlling salmonid culture. These represented "maximum and minimum" requirements as derived from various published sources (Figure 7.17).

Figure 7.17 GIS Approach Used for the Site Assessment Showing the Layers and Constraints Used



ii) For each mapped cell covering Camas Bruaich Bay a real value was allocated for each of the layers (parameters).

iii) These real values, for each of the six mapped parameters, were then converted to ranked score layers according to their suitability for salmonid culture.

iv) A "total shelter score" was then established for each cell by summing the three mapped layers showing depth (bathymetry), fetch and currents. Any cells which fell outside the "maximum - minimum" constraints (see Figure 7.17) for any of these three parameters, were eliminated from possible salmonid culture considerations.

v) A "total water quality score" was also established for each cell by summing the three mapped layers showing salinity, temperatures and dissolved oxygen. Consideration was also taken of variations between high and low tides and between surface and bottom readings. Again any cells which had values outside of the desirable constraints were eliminated.

vi) A Boolean process of intersection between the "total shelter" map and the "water quality" map was used to produce a ranked map of overall suitability of the bay for salmonid culture.

vii) From this map the total area of the bay which fulfilled culture requirements was calculated.

Though it was not possible to establish an exact carrying capacity of fish for this calculated area, sensible approximations could be deduced.

Results/Conclusions

These were produced under a number of sub-headings, mostly covering the main salmonid culture parameters:

i) *General Site Location.* This was considered well suited to mariculture since it had good road and power supply access. Labour and other economic inputs could be readily obtained from nearby Oban. There was no potential pollution from land-based activities and there were no tourist pressures or ecological limitations.

ii) *Water Exchange.* Using two recommended equations, full flushing times for the bay were calculated as 1.3 days or 2.5 days. The tidal range was 3.3 meters and the mean hourly supply of seawater was calculated as 52 140 m^3 per ha.

iii) *Wind.* Maximum wind speeds were registered as 33.0 knots in July (from the N.E.) and 45.7 knots in December (from the N.W.)

iv) *Fetch.* The three longest fetches were 4.44 kms (from the N.W.), 3.42 kms (from the N.E.) and 2.37 (also from the N.E.). Fetch-lines were drawn, having a width of 60 meters, across the bay on these axes and the areas they covered were considered as being unsuitable for cage location. This excluded 45.5% of the bay as being too exposed.

v) *Wave Height.* Using the known data on wind speeds and fetch, estimated maximum wave heights of between 0.4 m and 0.8 m were calculated (for different fetches) using established formulae.

vi) *Bathymetry.* The mean bay depth was calculated as 6.8 m and the maximum depth recorded was 40 m. 46.5% of the bay had depths considered suitable for cage culture, i.e. 6 to 12 m. Figure 7.18 shows the "OSU-MAP" output indicating locations having suitable bathymetry.

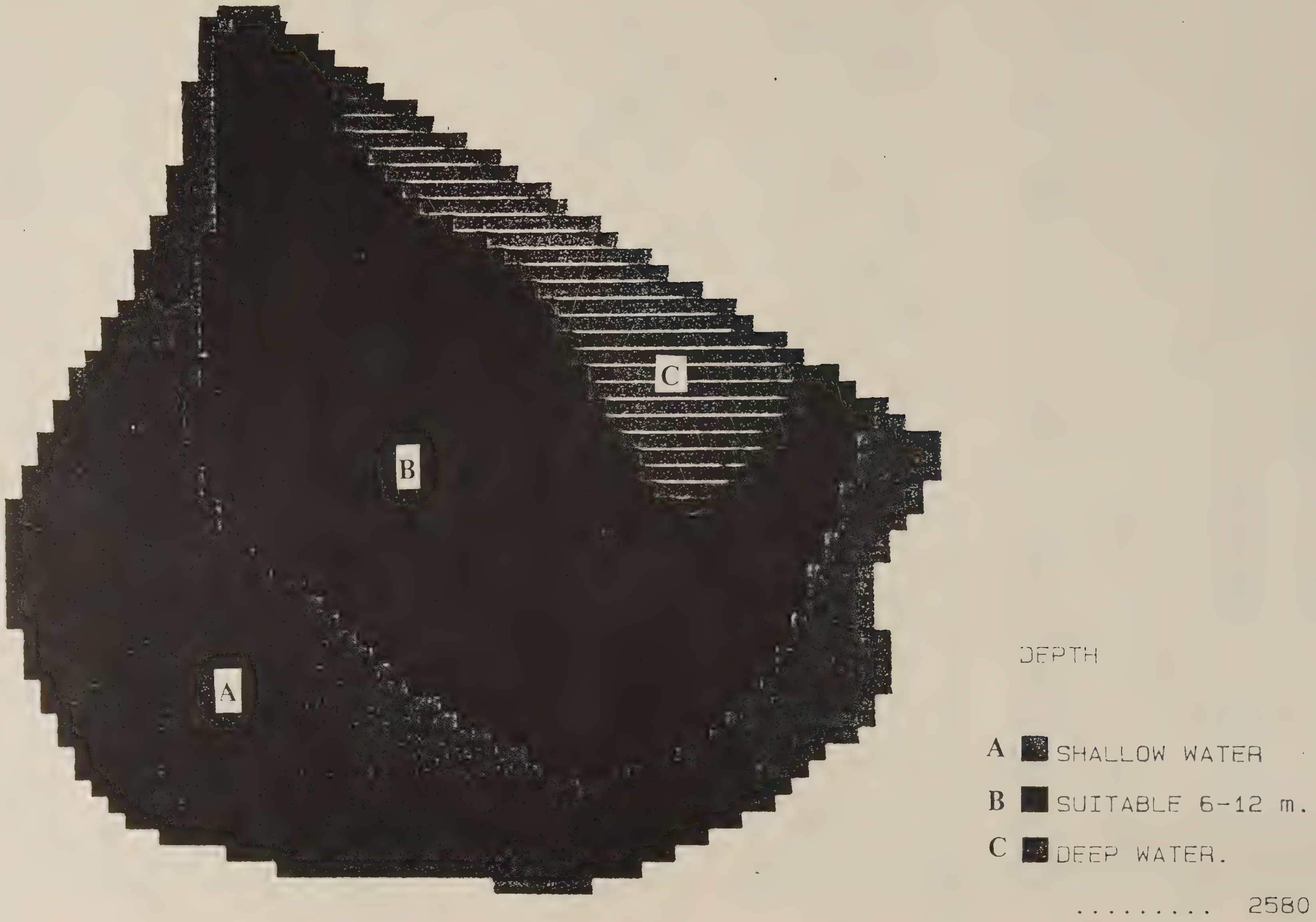
vii) *Currents.* The bay exhibited an anti-clockwise current with a highest velocity of 0.138 m per sec. Only 16.5% of the bay had current speeds which were considered as best suited for cage culture, mostly in the central/eastern area.

viii) *Sheltered Area.* As a result of the GIS calculations, an area of 3.11 ha - or 15.8% of the bay - was found to be suitably sheltered, mostly in the center of the bay.

ix) *Water Quality.* Though there were spatial variations in quality, none of the parameters exhibited values which were inappropriate to salmonid culture. Only for salinity readings (in the vertical water column) was it possible to show that some areas were better than others, i.e. 13.4% of the central bay area had high salinity variations which were relatively adverse.

The results of the Boolean intersection indicated that only 0.71 ha (3.6%) of the bay was considered as being totally suitable for cage culture - this was in the southern/central area. It was estimated that this would provide a mean realistic carrying capacity of 98 tons of fish, i.e. in two rows of 7 x 400 m^3 cages with a mean stocking density of 17.5 kg per m^3.

Figure 7.18 Map Showing Suitable Depths for Salmonid Cage Culture in Camas Bruaich Bay, Scotland


C
B
A
DEPTH
A SHALLOW WATER
B SUITABLE 6-12 m.
C DEEP WATER.
.... 2580

When comparing the two scales at which data were input to the GIS, i.e. 10 x 10 m and 25 x 25 m cells, it was found that the latter had too coarse a resolution to provide satisfactory

results relative to the area being studied. When comparing the manual assessment of the bay with the GIS assessment, then the former found that a higher proportion of the bay would be suited to cage culture, i.e. up to 1.44 ha, and that up to 160 tons of fish per cycle could be produced.

However, the manual assessors considered that production would be more restricted in its general location. The manual assessment took a mean time of 36 hours per assessor v 19.6 hours for the GIS method. Though there were increased costs incurred in this study from using GIS rather than manual methods, this did not take into account the fact that GIS tools and data, once purchased and if maintained and updated, could be used many times and in a range of associated scenarios.

Discussion/Recommendations

It was clear that Camas Bruaich Bay was generally a suitable location for cage culture, though only in a very limited area. The author suggested that the farming of trout might be preferable to salmon, since they are more tolerant of the large daily salinity variations, though this also might need to reflect considerations relative to prevailing market conditions. It was recognized that different results would have been obtained had different parameters for assessment been incorporated, had different analytical approaches been adopted or had different levels of accuracy been applied.

The author interestingly suggests that research is needed on the optimum scale (resolution) for any GIS study. In this particular type of study considerations need to be given to a resolution such that the scale is a certain ratio of the area being studied. Thought must also be given to the ordering of certain systems operations, i.e. since the result of Boolean operations are order dependent, and to the range of numbers allocated as values to the particular parameters.

Study 12

TITLE: Where are the best opportunities for fish farming in Ghana? The Ghana Aquaculture Geographical Information System as a decision-making tool.

AUTHOR: Kapetsky, J.M., Wijkstrom, U.N., MacPherson, N.J., Vincke, M.M.J., Ataman, E., and Caponera, F.

PUBLICATION and DATE: *Field Technical Report 5*. FI:TCP/GHA/0051. FAO, Rome. 1990.

Introduction/Objectives

Fish farming in Ghana, with only about 109 ha of pond surface in operation, is little developed at present. In fact, an attempt to stimulate fism farming in the early 1980s failed largely because of poor planning and lack of technical support. About 23% of the pond surface, amounting to nearly 400 ponds, have since been abandoned. In order to make a new start at aquaculture development the Government of Ghana requested help from FAO to undertake a Technical Cooperation Programme project with the objective of devising a technical assistance and investment framework for aquaculture development. Activities of the project included analyses showed that the most promising aquaculture endeavour would be the farming of tilapias and catfish in ponds using manures and agricultural byproducts as inputs.

Accordingly, the GIS was designed to assess the capability of each of 110 administrative districts to provide opportunities for fish farming in ponds. The district was chosen as the unit in which to portray the final results for several reasons. Firstly, the district is the lowest order of organization from which much of the data useful to assess development potential are reported. Secondly, decisions on development are often implemented at local government level.

Methods/Equipment

An analysis was first made of the essential "criteria" for fish farming development, and the spatial data pertaining to these criteria were described. These criteria are:

i) *Water.* This can be obtained from irrigation scheme supplies, rainfall runoff, river channels and from groundwater sources. The first of these was ignored since it was beyond the remit of the study and the latter because of potential problems of water disposal (pond drainage). An indication of water availability was obtained by constructing a map which was the result of subtracting the dry season water evaporation rates, for all areas in Ghana, from the mean annual rainfall figures. The resulting map was represented by areas which effectively showed an "ample" (>500 mm), "adequate" (401 - 500 mm), "marginal" (301 - 400 mm) or "insufficient" (<300 mm) water balance. Any fish farming would be very risky in areas having <300 mm of available water and there would be "added costs" in areas having from 301 - 400 mm.

ii) *Land.* Since it would be unavailable for development, all land in various "reserved" categories, plus the area of Lake Volta and some coastal lagoons (totalling 19% of Ghana's surface), were removed from consideration. Soil quality was also an important "land" criterion. Soils were classified according to their suitability for aquaculture, into four categories - "good", "fair", "poor" and "unsuitable" (Figure 7.19). Because the soil maps used for classification were at a very large scale, and therefore would not show those areas adjacent to rivers and streams having good alluvial soils, then these areas were incorporated in the soil polygons showing "poor" and "unsuitable" areas, i.e. as 1 km wide buffers along the river courses.

iii) *Economics of Inputs and Markets.* The availability of four inputs was considered - "cattle", "pig" and "poultry" manures and "rice bran". These taken together determined whether sufficient inputs were available to support fish farming at a prescribed minimum level. The spatial distribution of the combination of these inputs was mapped and tabular data for each of the 110 districts in Ghana (showing a numerical input index) was compiled. Likewise, a map was constructed and tabular indices were compiled showing the distribution of markets (defined as the ability to absorb tilapia and mudfish). Data for these were derived from the population distribution, population growth rates, patterns of fish consumption, the supply of tilapia and mudfish and road distances to the nearest urban market centers.

iv) *Welfare.* The best available indicator of this criterion were statistics showing the number of smallholder households below basic needs income. Data could only be derived for Ghana's ten main regions, but values (in quartiles) were allocated in tabular form to each district.

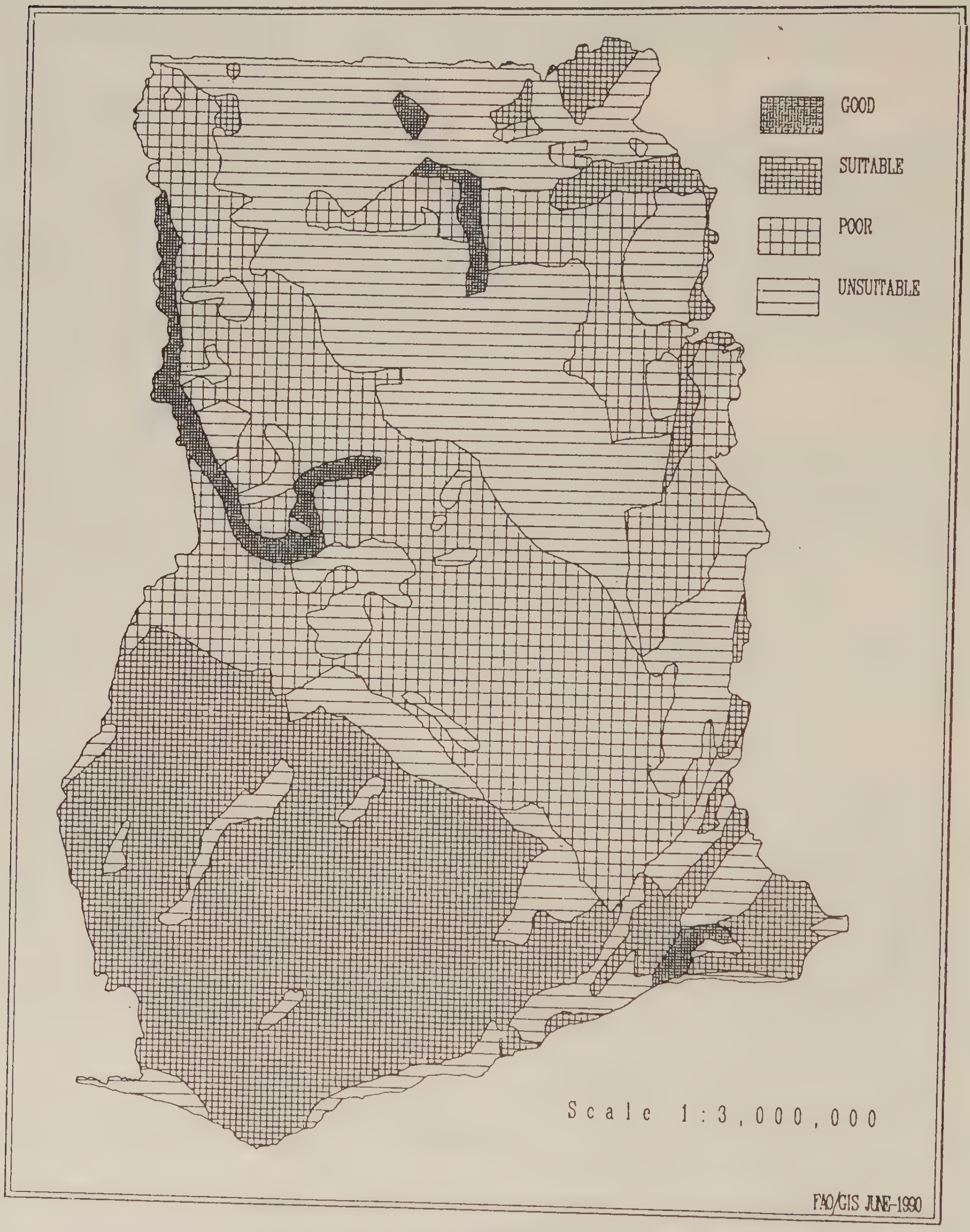
v) *Extension Services.* A map was compiled for the ten main regions based on the number of fishery officers per surface area of fish ponds. Values were also assigned to districts by quartiles.

vi) *Agglomeration.* This is a measure of the positive influence of existing farms on the potential development of new farms. An index was calculated based on a ratio between the size of the district and the surface area of the existing fish ponds. Indices were tabulated into five categories.

vii) *Development.* As an indicator of this the density of the road network in each district was calculated and values were assigned to districts by quartiles.

Each of the above criteria were weighted according to their estimated importance to fish farming, and then incorporated into the model. Several steps were involved:

Figure 7.19 Soil Suitability for Pond Development in Ghana



i) The land and water criteria were integrated to create a "Land and Water Index" (KL) for each district using the equation:

$$KL = 1.5(G \times R + I \times 3) + (S \times R)$$

where G = km^2 of soils rated "good" for ponds plus km^2 of alluvial soils adjacent to rivers.
R = "effective rainfall" taking values 0.15, 1.15, 2.15 and 3.15 corresponding respectively to "insufficient", "marginal", "adequate" and "ample" water balances.
I = km^2 of irrigated area.
S = km^2 of soils rated as suitable for ponds.

The author gave justifications for the weightings given. Output was in both map and tabular form.

ii) The data for agglomeration, extension and development were integrated to produce an "Other Factors Index" (KF). In this the criteria for agglomeration was given twice the weighting of the others. Again, both map and tabular data by districts was derived.

iii) In order to portray a range of development opportunities, four integrated models were generated by applying different criteria combinations and weightings, i.e.

A) Model K1 = KL + 0.5(KI + KM + KW + KF).
B) Model K2 = KL + 0.5(KI + KM + KF). (see Figure 7.20).
C) Model K3 = KL + KI + KM + 0.5(KW + KF).
D) Model K4 = KL + 0.5(KI + KM + (KF - AG)).

where KL = the "Land and Water Index".
KI = Input indices (manures and rice bran).
KM = Marketing indices (population, fish consumption and distance to main markets.
KW = Welfare indices (incomes).
KF = "Other Factors Index" (agglomeration, extension and development)
AG = Agglomeration indices only.

The different emphases can be clearly inferred and Model K4, by excluding agglomeration, gives consideration to districts that otherwise may have good opportunities for development but in which there is presently little or no fish farming.

Results/Conclusions

The results were output from the GIS in three main forms:

i) Tabular data which ranked the 110 districts in Ghana according to each criterion, or to combinations of criteria.

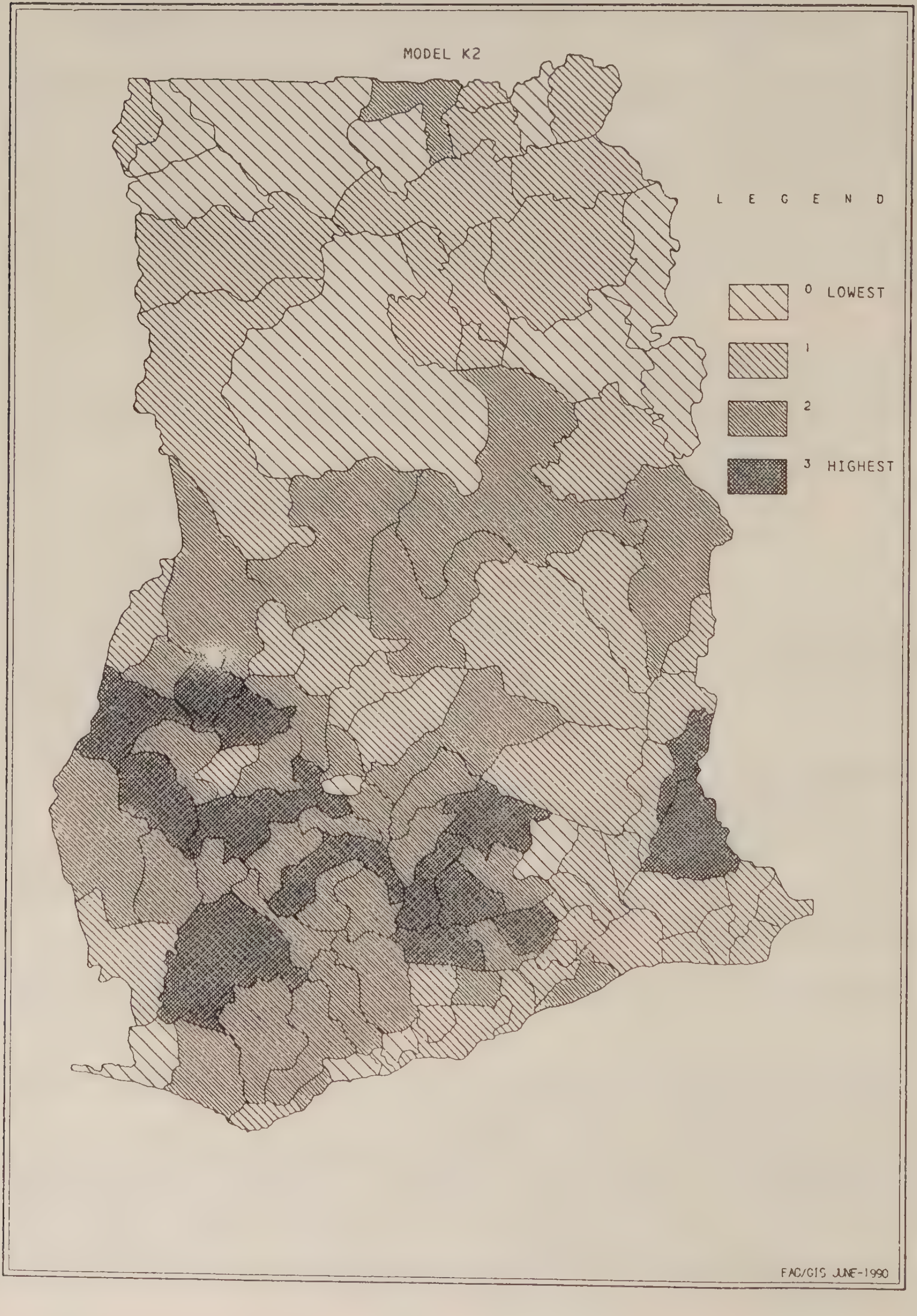
ii) Mapped data, showing criteria distribution by district or region, usually in four classes.

iii) Frequency distributions showing, for each criterion or a combination of same, the number of districts against index values.

A spatial manifestation of the KL model ("Land and Water Index") clearly shows southern Ghana to be preferable for this criterion. Here many areas have an ample water balance and, though little of the area is rated as having "good" soils, the majority of the SW has soils classified as being "suitable". The fact that little irrigation water is available should not be a deterrent here, especially if the various other criteria are suitable.

Areas having the best inputs (KI) were shown to be mainly in northern Ghana, largely because cattle dominate here. The spatial disposition of markets was more diverse, though there was a concentration in the central south and the central west. Overall relatively few districts offer good economic prospects for fish farming in that a high availability of inputs and good markets occur together. This means that a high proportion of the fish produced might need to be transported to meet market demands. And likewise, few districts offer significant opportunities for development from the "Other Factors" (agglomeration, extension and development).

Figure 7.20 Map Showing Distribution of Fish Farming Potential in Ghana According to Criteria for Integrated Model K2



Looking at the "integrated models", showing a range of development opportunities, a variety of districts emerge as being potentially superior. However, the S and SW areas are favoured for fish farming development by all the models. Model K1 strongly favoured the central southern (Ashanti) area, and Model K2 strongly favoured the south (see Figure 7.20), i.e. it penalizes the north because the model omits welfare considerations which are adverse here. Model K3, which emphasizes the economic aspects rather than welfare, again shows much of the south to be favourable, though some of the north now benefits because of advantageous inputs. By excluding agglomeration, Model K4 highlights areas which would be good for fish farming, though at present it is little practised. Clearly the provision of extension services here would be important. Again, southerly areas are dominant. To emphasize districts which did well on all the models, tabular data was produced showing the number of times that high scoring districts appeared in all models.

Discussion/Recommendations

When interpreting the results it is important to place them within contextual constraints. Thus, much of the data for this study was obtained from other organizations within Ghana, and they were largely estimates having an unknown error content. A number of assumptions were also necessarily made, such as the distribution of local markets for fish. The weightings used were based on experience gained in many developing countries since actual data on which weightings could be made were lacking. Thus the results could be interpreted only as "indicative".

As a follow up to this study, the author recommends a study of the factors which have influenced the development (or non-development) of fish farming throughout Ghana. The results of this could be used to refine the present models. It is also important that a detailed study be made of the availability of crop by-products, especially oil palm, since their known availability could greatly enhance development opportunities for some districts. The approach used in this study need not be confined to tilapia and catfish farming in ponds - it could be extended to other kinds of farming systems and to culture-based fishing systems.

Study 13

TITLE: "The Use of GIS for Coastal Resources Study: Some Case Examples"

AUTHOR: Kam Suan Pheng

PUBLICATION and DATE: *Tropical Coastal Area Management*; Vol.4, No.2. 1989.

Introduction/Objectives

This particular study has been included because it is using GIS methods in a developing country to look at social factors, as well as economic ones, in a coastal environment. It has become clear that the long-term acceptance of measures to increase fish production may depend as much on the ability of the production system to be integrated into a community socially as integrated economically.

The Malaysian Coastal Resources Management Project (CRMP) is concerned with identifying a number of socio-economic variables which might influence developments, in this case in a 5 km coastal zone, around the southern Johore area at the tip of the Malay peninsula. The CRMP is currently building up a data base on the coastal area using a variety of sources. It presently has data on a large number of socio-economic variables including population, employment statistics, income levels, educational background, infrastructure and public

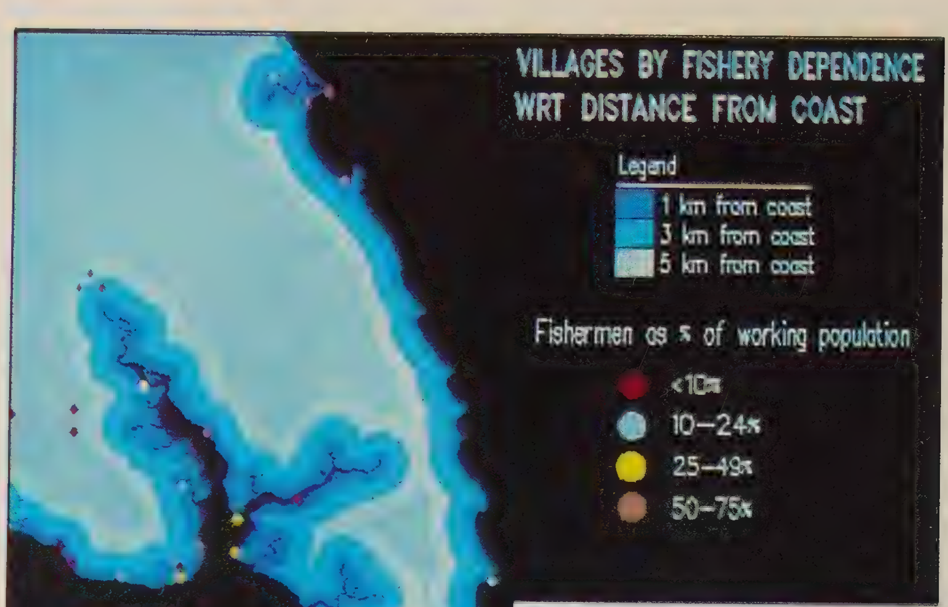

VILLAGES BY FISHERY DEPENDENCE
WRT DISTANCE FROM COAST
Legend
1 km from coast
3 km from coast
5 km from coast
Fishermen as % of working population
<10%
10–24%
25–49%
50–75%

Figure 7.21 Fishery Dependence of Villagers in Coastal Settlements in Southern Johore

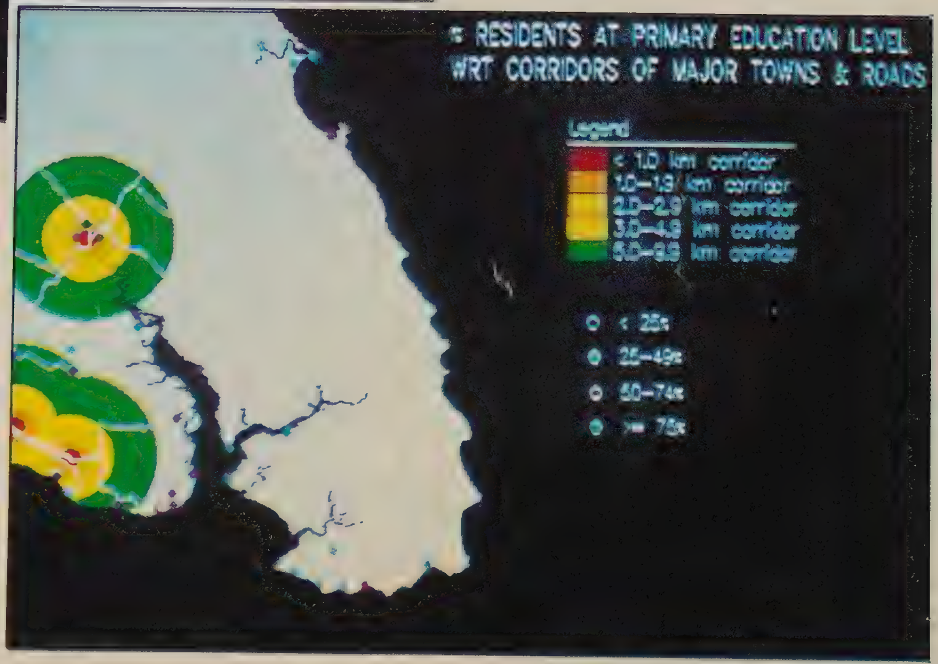

% RESIDENTS AT PRIMARY EDUCATION LEVEL
WRT CORRIDORS OF MAJOR TOWNS & ROADS
Legend
< 1.0 km corridor
1.0–1.9 km corridor
2.0–2.9 km corridor
3.0–4.9 km corridor
5.0–9.9 km corridor
< 25%
25–49%
50–74%
>= 75%

Figure 7.22 Educational Attainment by Distance from Main Towns and Roads in Southern Johore

amenities. Data on a total of 84 variables was obtained from a survey carried out by the Johore State Economic Planning Unit. The CRMP is using the Spatial Analysis System (SPANS), a microcomputer based GIS package. Point, line and polygon geographic data on the variables, plus associated attributes, are being used for various forms of spatial analysis and mathematical modelling. As further layers of information are captured, it is hoped that more sophisticated manipulations, and therefore more perceptive analysis possibilities, will be achieved. The author briefly outlines a number of studies which illustrate GIS applications to pertinent issues.

Methods/Results

The first study was to see if the economic activities of the village populations was related to distance from the coast. The location of 84 villages within the delineated 5 km coastal zone was Figure 7.21 Fishery Dependence of Villagers in Coastal Settlements in Southern Johore digitized into SPANS. The GIS was then used to create 1, 3 and 5 km corridors from the coastline, and the village locations were indicated (Figure 7.21). It can be seen that the majority of the villages with a high dependence on fishing are concentrated within the first kilometer of the coast.

The next study aimed to quantify the concept of accessibility to a place and, hopefully, to correlate that with the development status of the place. SPANS was used to create circles of increasing distance from major towns, as well as corridors for major roads to represent remoteness from, and accessibility to, the growth centres. The villages could be successively displayed and overlayed using various social and economic criteria. The results (Figure 7.22) clearly indicate a high visual correlation between road accessibility, town location and educational attainment. The more isolated coastal villages along the Johore River estuary have the lowest percentage attaining secondary education. It was also found that the occupational structure of settlements reflected their accessibility to road transport - those closest to roads showed a high urban occupational dependence.

In a final study the effects of changing land use was exemplified. A land use map produced by the Ministry of Agriculture in 1974 was digitized into the GIS, and another was done from air photo interpretation in 1986. The two maps were overlayed and it was shown that only 40% of the original forest area in 1974 remained in 1986. Replacement land uses were indicated. The monitoring of land use change is important, not only in the coastal zone but also in the river basin hinterland, because the impacts of land use up-river can affect the quality and use of resources down-river or along the coast. It allows for the spatial examination of compatible and incompatible uses. This is especially important where coastal zone land is under the control of various organizations, each concerned with only one particular use.

Discussions/Recommendations

Through the integration of data from various sources, the CRMP has been able to identify existing and potential conflicts between land and resource uses, and to highlight the important social distributions and relationships. These are graphically and effectively shown when displayed in a map or series of maps, especially if spatially related to environmental impact indicators like water quality, forest clearance or road construction. The information thus mapped can also be used at the planning stage to zone and allocate resource use such that incompatibilities can be avoided.

Study 14

TITLE: "Development of a Dispersant-Use Decision Making System for Oil Spills in the U.S. Gulf of Mexico"

AUTHORS: Trudel, B.K., Belore, R.C., Jessiman, B.J. and Ross, S.L.

PUBLICATION and DATE: *Application Research Paper No.12*; S.L.Ross Environmental Research Limited, Ottawa, Ontario, Canada.

Introduction/Objectives

Work was originally carried out in the early 1980s for the Canadian Department of the Environment, to produce a "step-by-step" guide for assessing quantitatively the impact of oil spills in a marine environment. Effects were monitored for untreated oil spills and for those treated with chemical dispersants and a comparison was made. The marine environment included a range of biological resources and different kinds of shorelines. The proportion of the population of the resource affected, or of the coastline, was calculated on the basis of the movement of the oil, the sensitivity of the resource and the vulnerability of the specific resource at the time of year of the spill. The project was "tested" for the Arctic (Beaufort Sea) area and the results were used to develop a dispersant use contingency scheme for the area should a spill ever occur.

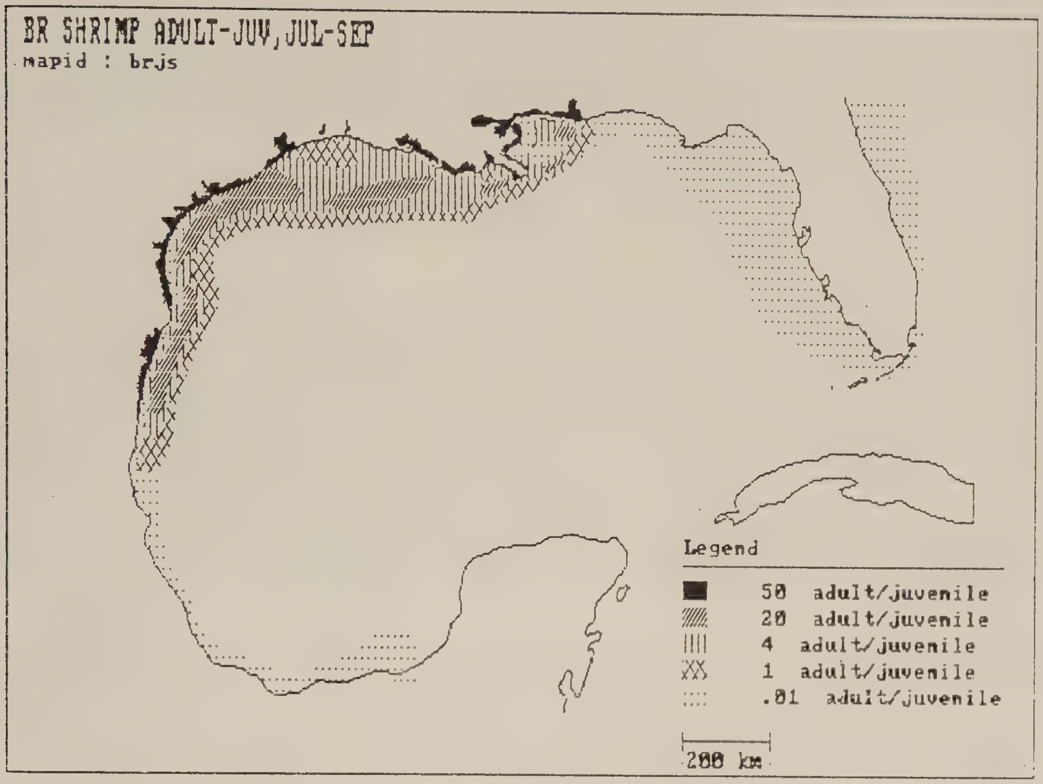
Using similar methods, the U.S. oil industry consortium (MIRG) decided to initiate such a precautionary scheme for the coastal states on the Gulf of Mexico. Because of the complexity of the Gulf environment, and because of the number of hypothetical oil scenarios provided for, it was decided to replace the "simple, hand calculation approach" with a more sophisticated, computerized system, i.e. incorporating a full GIS analytical capability.

Methods/Equipment

A computerized map of the untreated spill was produced showing the predicted location and concentration of the spilled oil as a function of time after the initial discharge. The map was produced using an "in-house" oil spill fate model, developed by S.L. Ross Environmental Research, that accounted for all the major oil spill processes (advection, spreading, evaporation, dispersion, etc), oil types (heavy, medium or light) and which generated areas, volumes and thickness of oil slicks. Different wind conditions and the time of year (affecting currents) were also considered. The model has been tested, with good correlations, against major oil spills which have previously been documented.

This map was then compared (by overlaying) with a series of computerized maps of 70 important Gulf resources that might suffer from the effects of the spill. Figure 7.23 shows an example of one resource map. The 70 Gulf resources were shortlisted from a preliminary list of over 200, and the list contained a wide representative sample of ecologically and economically important resources, from a variety of biogeographic regions, in the eight categories of invertebrates, finfish, birds, mammals, reptiles, biologically-sensitive habitats, shorelines and property. For resources whose various life-stages have dramatically different habitats, or different degrees of vulnerability to oil spillages or dispersants, then separate distribution maps were drawn up. It was also necessary to establish toxicity criteria, based on the toxic mode of action (chemical or physical) and reflecting likely natural exposure conditions, for all major life stages for each resource (where appropriate).

Figure 7.23 The Geographic Distribution of the Northern Gulf Brown Shrimp Population



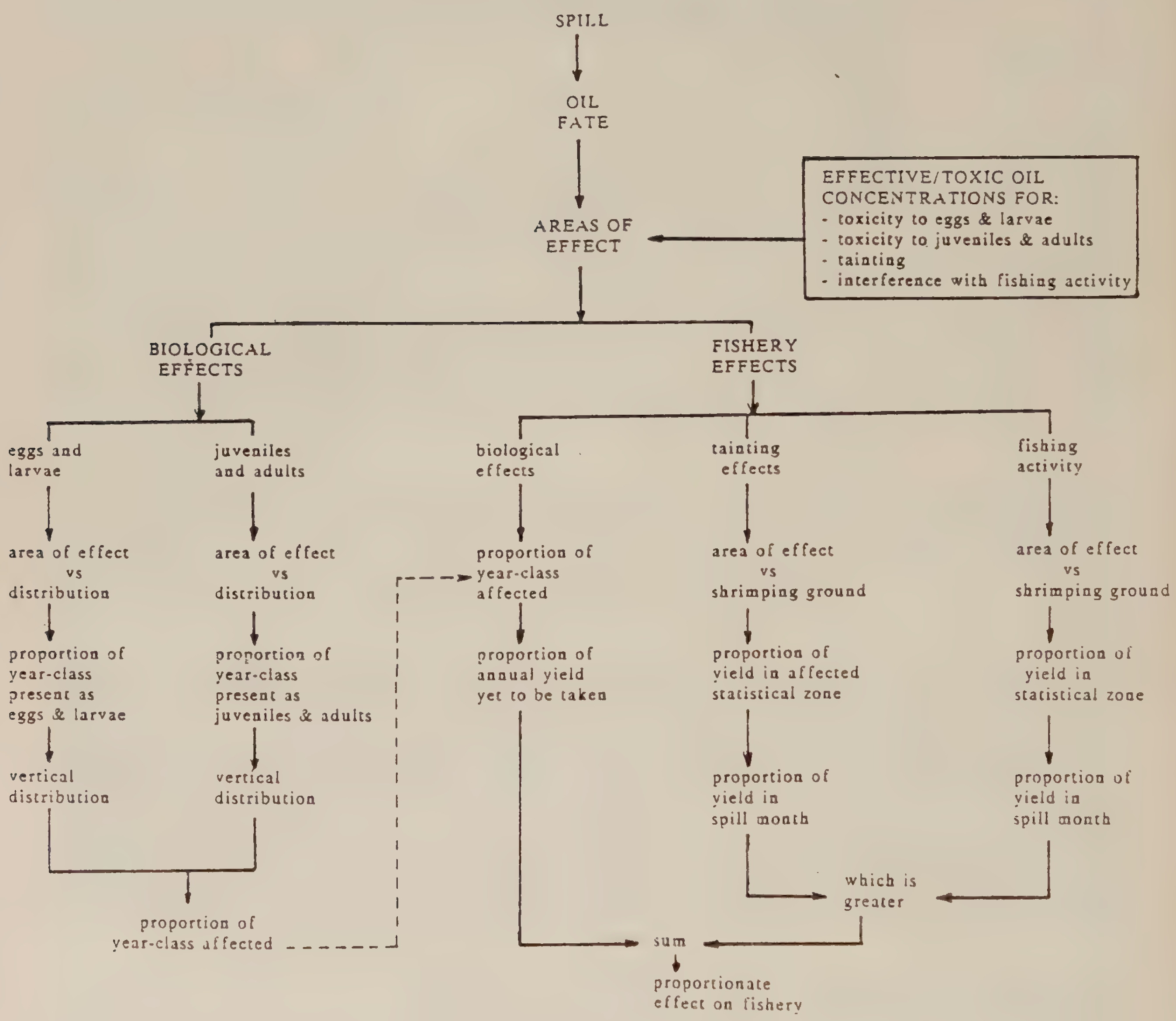
A GIS with extensive spatial analytical capabilities was then used to calculate the proportion of each resource that was affected by the spill at specified levels of oil concentration. The GIS software package used was supplied by Tydac Technologies (SPANS - Spatial Analysis System) running on a PC. A digitized version of the "in house" oil fate model was coupled to the SPANS software to generate a database for oil dispersal mapping purposes. Using a series of resource specific impact assessment algorithms that linked information on oil concentration and resource sensitivity, estimates of the impact were then computed for each resource. An example algorithm for brown shrimp is shown (Figure 7.24). Here the "oil fate" is combined with the "effective/toxicity" criteria to produce unique mapped areas for each of four effects. Both biological and fishery effects can then be computed using the algorithm. The entire procedure is repeated for the same spill if it were to be chemically dispersed.

Results/Conclusions

Having computed the effects of treated and untreated oil on all resources, the results can be summarized so that the user can quickly determine whether dispersants can reduce the overall effect of the spill. This summary is achieved by listing side-by-side the effects of the treated and untreated spills on the key resources. The effects on each resource are reduced to the semi-quantitative terms - negligible, slight, moderate and major. The user can then prepare arguments both in favour and against the use of dispersants, and ultimately formulate a logical and defensible decision. The system is also designed to provide, on command, details of the computed impact on each resource (effects on life-stages and fisheries) as well as the biological and toxicological input and the oil fate data that went into the impact calculations.

First indications are that it will take less than one hour to produce a fully documented impact assessment and dispersant decision for a spill in the Gulf involving the 70 key resources. The system has recently been made more "user friendly" so that it can be operated easily and quickly during actual spills.

Figure 7.24 Algorithm for Computing Effects of Dispersed or Untreated Oil on the Brown Shrimp Stock and its Associated Fishery


SPILL
OIL FATE
AREAS OF EFFECT
EFFECTIVE/TOXIC OIL CONCENTRATIONS FOR:
- toxicity to eggs & larvae
- toxicity to juveniles & adults
- tainting
- interference with fishing activity
BIOLOGICAL EFFECTS
FISHERY EFFECTS
eggs and larvae
juveniles and adults
biological effects
tainting effects
fishing activity
area of effect vs distribution
area of effect vs distribution
proportion of year-class affected
area of effect vs shrimping ground
area of effect vs shrimping ground
proportion of year-class present as eggs & larvae
proportion of year-class present as juveniles & adults
proportion of annual yield yet to be taken
proportion of yield in affected statistical zone
proportion of yield in statistical zone
vertical distribution
vertical distribution
proportion of yield in spill month
proportion of yield in spill month
which is greater
proportion of year-class affected
sum
proportionate effect on fishery

Study 15

TITLE: "Use of a Geographic Information System as a Conservation Tool for Rivers in Virginia, U.S.A."

AUTHORS: Angermeier, P.L. and Bailey, A.

PUBLICATION and DATE: 1991.

Introduction/Objectives

Conservation efforts for most aquatic species are widespread throughout the United States by both state and federal agencies. Approximately 350 species of freshwater fishes are protected legally over part or all of their geographic ranges in the U.S. and Canada and direct expenditures by U.S. agencies on 114 federally protected fish and mussel species totalled about $6 million in 1989. However, current conservation efforts appear inadequate to preserve aquatic biodiversity over the long term, with far more species showing a decline in population status from 1979 to 1989 than those showing an improvement. Thus, if biological conservation goals are to be achieved, management agencies must increase the effectiveness of their conservation programs.

Effective management of rare species will require detailed information on many environmental variables covering a broad array of temporal and spatial scales. In particular, environmental managers need to know where the biota of concern live, where threats to the biota may occur and the extent to which known threats will adversely affect the biota. Given this information, managers can develop cost-effective strategies to minimize further losses of biodiversity or to restore ecological systems which are already degraded. The great volumes and diversity of data required to manage biodiversity effectively necessitates the use of computer-assisted analytical tools such as GIS, i.e. so that appropriate management decisions can be made quickly and confidently.

This paper presents a basin level approach to the conservation of riverine biodiversity. Specific objectives include:

i) To describe components of a GIS developed for riverine systems in Virginia, U.S.A.

ii) To illustrate conservation applications of the GIS in the Clinch River basin within Virginia.

iii) To identify additional potential applications relevant to conservation of riverine systems.

The Clinch River basin was selected for a detailed examination since it supports a large array of aquatic fauna, many of which are rare or endemic, and because this basin is particularly vulnerable to various kinds of potentially detrimental human activities.

Methods/Equipment

A "river reach" database was set up for the GIS, containing data on 3700 stream reaches within the state of Virginia, and 150 reaches within the Clinch River basin. The database comprised of the list of stream reaches, each with upstream and downstream co-ordinates (latitudes and longitudes) that typically occur at stream confluences, mouths, etc. Each reach is identified by a unique hierarchical code that specifies region, sub-region, river basin and sub-basin. Data for the "river reach" database was obtained from that already held by the U.S. Environmental

Protection Agency, plus additional data taken from 1:24 000 USGS topographic maps covering Virginia.

A base map was compiled (digitized) from a USGS Hydrological Map of Virginia at a scale of 1:500 000 and this showed river basin watersheds (boundaries) and the state border. Other files (or "layers") were established showing land use by the five categories of wetlands, forest, urban, agricultural and barren - data for this was obtained from USGS Land Use and Cover Maps at 1:250 000 scale. Additional geographic information such as elevation, stream order number, water quality, location of active mines, etc., were obtained from various state and federal sources. Textual data on a total of 35 geographic fields was eventually compiled for all the 3700 "river reaches" and unique reach codes were assigned so that the reaches could be topologically related to the geographic fields.

Biological data, covering 16 different fields, were collected from a variety of sources to make up a "fish collection" database. Included in this were all federally protected species as well as numerous species not currently protected. The database also contained records of approximately 3000 fish collections made by fisheries personnel throughout Virginia since 1960, and these were registered to stream reaches so that fish species by location could be analysed and displayed.

Land use along streams was analysed by defining a 1 km "buffer" on both sides of each reach, then computing land use within the buffer. For reaches supporting rare species, the buffer was also searched for coal mines and municipal/industrial outfalls.

The GIS was based on ARC/INFO software running on a DEC Micro-VAX II minicomputer and on PC ARC/INFO running on an IBM PC/AT. The bulk of the data was managed in an Advanced Revelation (AREV) software system, which allowed more efficient storage and retrieval of data than did INFO. Data were transferred as needed from AREV to ARC/INFO in ASCII text files for purposes of spatial analysis and display.

Results/Conclusions

In a study on this scale a wide variety of results were obtained. To give an indication of GIS capability, we have selected a cross-section of those applying to the Clinch River basin study area:

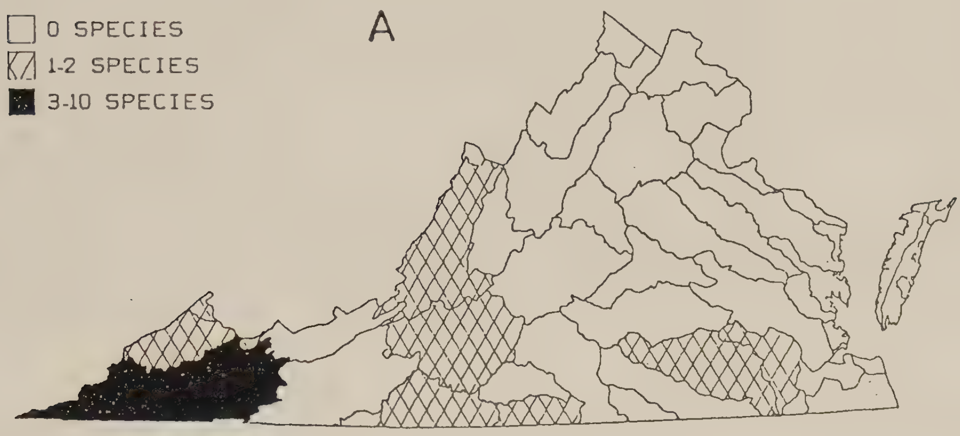
i) Although it occupies less than 8% of Virginia's land area, the Clinch River basin supports 50% of the fish species and 79% of the mussel species in need of conservation, as well as an exceptional diversity of fish species that are not currently in need of protection. Figure 7.25 shows threatened and endangered aquatic species areas in Virginia (the Clinch River basin is that area shaded black in map B). These patterns indicate that the basin should be a focal point of programs aimed at biota conservation in Virginia.

ii) Many potential sources of point-source pollution occur in the Clinch River basin, e.g. coal mining is a major activity in certain portions of the basin, with at least 12 active mines being located within 1 km of stream reaches supporting rare species (Figure 7.26). Additionally, 11 of the 48 industrial or municipal effluents legally discharged into the basin enter reaches that support rare species.

iii) Although only 2.1% of the Clinch River basin in Virginia is in urban land use, 4.9% of the land within 1 km of streams is urban. The proximity of urban development to streams increases the probability of adverse impacts on the biota. Agriculture, which occupies 30.7% of the land area in the basin, represents the most extensive disturbance and the greatest potential for non point-source pollution.

Figure 7.25 Plots Showing the Distribution of Threatened or Endangered Fish and Mussel Species in Virginia

STATE T & E FISH SPECIES OF VIRGINIA


☐ 0 SPECIES
▨ 1-2 SPECIES
■ 3-10 SPECIES
A

STATE T & E MUSSEL SPECIES OF VIRGINIA

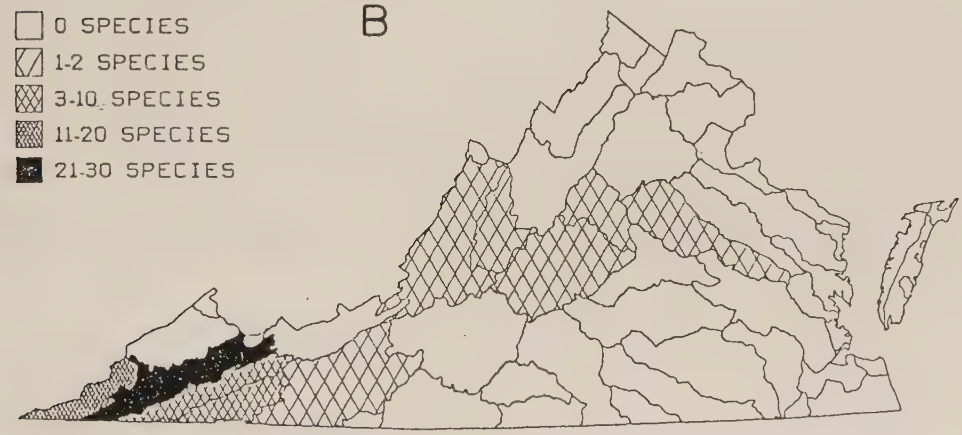
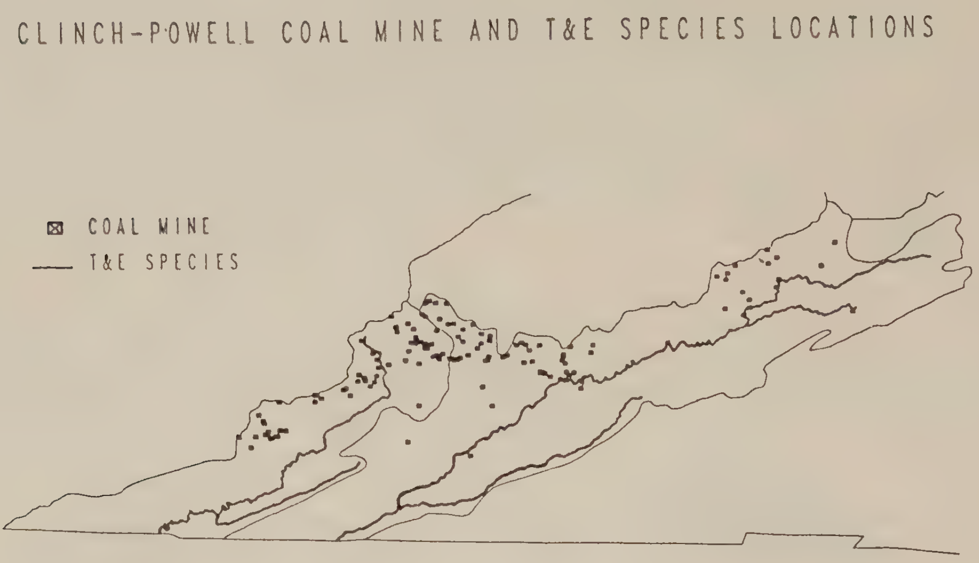

☐ 0 SPECIES
▨ 1-2 SPECIES
▩ 3-10 SPECIES
▩ 11-20 SPECIES
■ 21-30 SPECIES
B

Figure 7.26 Plot of the Clinch River Basin Showing Relationship Between Active Coal Mines and Streams Having Threatened or Endangered Species



iv) The extent of preserves and public lands and waters is inadequate to protect aquatic biodiversity in the Clinch River basin. Less than 10% of the basin is publicly owned, and virtually none of that land includes or is adjacent to reaches supporting rare aquatic species. Once these "gaps" in the potential for conservation are realized then management priorities can more easily be ordered.

Discussion/Recommendations

As a result of the wide-ranging findings of this survey suggestions were proposed for a comprehensive basin wide management plan. Such a plan should include:

i) State and federal protection of 14 fish and mussel species.
ii) Implementation of recovery plans for federally protected species.
iii) Reclamation of mined lands.
iv) Exclusion of livestock from streams.
v) Research on the mechanisms of impact on aquatic populations.
vi) Development and application of environmentally sound technology for coal production.
vii) Strict enforcement of pollution regulations for industries and municipalities.
viii) Development and implementation of "best management systems".
ix) Programs to educate citizens and landowners regarding riverine conservation needs.

It was further suggested that a GIS could help management practices by allowing for the visualization of spatial variations in physical features such as elevation, temperature, stream gradient, soil or geologic formations, topography and land use. Such information is often useful in understanding natural variations in biotic communities, as well as variations associated with human activities. A knowledge of spatial relationships among ecological processes, human uses of natural resources and environmental threats is critical to effectively designing protective areas or focusing other conservation strategies.

Study 16

TITLE: "Remote Sensing and Geographic Information System Techniques for Aquatic Resource Evaluation"

AUTHORS: Welch, R., Madden Remillard, M. and Slack, R.B.

PUBLICATION and DATE: *Photogrammetric Engineering and Remote Sensing*; Vol.54, No.2. 1988.

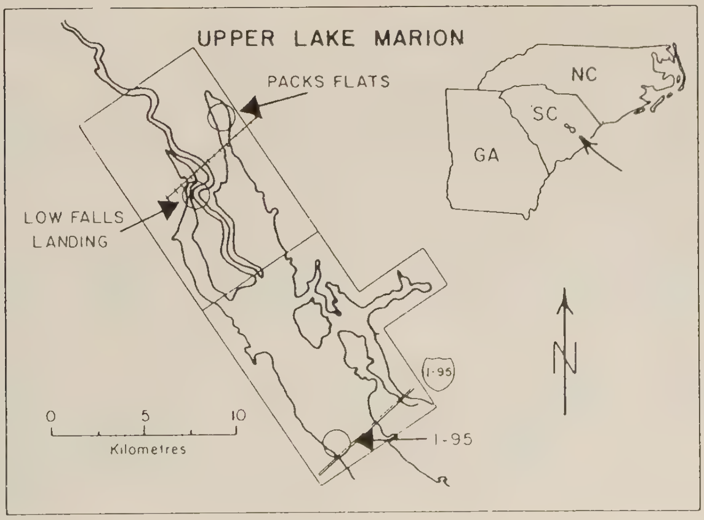
Introduction/Objectives

An important aspect of applied RS and GIS to inland fisheries potential could be to provide information on vegetation growth and water quality in various water bodies. This study is an example of the integration of RS and GIS, incorporating temporal airborne RS data and the use of a low cost GIS.

Concern for the future of major lakes and reservoirs within South Carolina, U.S.A., prompted the Dept. of Health and Environmental Control (DHEC) to instigate a comprehensive water quality study of the Santee-Cooper River basin. The focus of the study was on the relationships between the distribution of aquatic macrophytes and water quality in Lake Marion (a reservoir of some 45 000 ha.), i.e. to see whether changes in water quality would cause an increase in the already extensive aquatic vegetation and to promote its spread to other parts of the river basin.

Lake Marion was built in 1941 to provide hydro-electric power in South Carolina. The lake is relatively shallow and supports a diverse fish and waterfowl population, making it a popular recreation area. The specific study area was confined to upper Lake Marion, which extends approximately 23 km northwest of highway I-95 (Figure 7.27). Its physical characteristics include stable water levels, depths averaging less than three meters and high turbidity. Sediment from the Santee River inflow is deposited in the upper lake as the water velocity of stream flow decreases. The presence of aquatic vegetation in the lake further encourages deposition which, in turn, creates a favourable habitat for more plant growth.

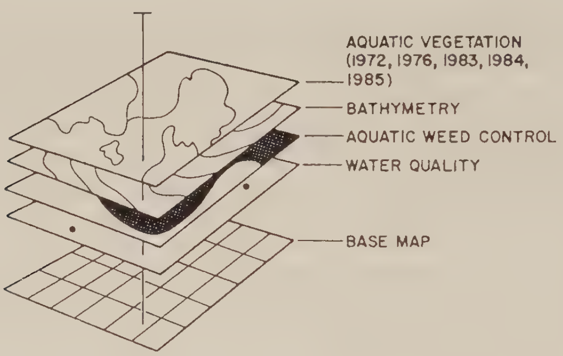
Figure 7.27 Location Map of the Lake Marion Study Area



Methods/Equipment

Various data bases for the upper Lake Marion area are being constructed, and the layers included are depicted in Figure 7.28. Maps of the distribution of aquatic macrophytes were developed from colour infrared aerial photographs in film transparency format recorded in 1972, 1976, 1983, 1984 and 1985. The photographs were interpreted under high magnification, and polygons representing the different types of aquatic vegetation were delineated on clear polyester overlays registered to the aerial photographs. Table 7.9 summarizes the photo characteristics of aquatic macrophytes found in Lake Marion, and the main mapped categories are the four main species types shown. Maps of 1:10 000 or 1:24 000 scale were produced, depending on photograph scale, and then digitized. A framework of ground control points was identified and, using the GIS, the maps were registered with each other to the Universal Transverse Mercator (UTM) projection. All maps were then transformed to a 1:10 000 scale. Maps depicting changes in aquatic macrophyte distributions were produced by registering maps of different dates to one another and delineating areas of change.

Figure 7.28 Data Sets in the Lake Marion GIS Data Base



A bathymetric map of Lake Marion produced from fathometer recordings taken from boat surveys along transects of the lake was obtained from the U.S. Geological Survey. Maps depicting the area of herbicide applications were prepared for each year from 1982 to 1985 (Figure 7.29), i.e. based on information from the DHEC and the South Carolina Water Resources Commission.

Long-term water quality sampling stations in the lake cluster in three general areas (ringed in Figure 7.26), and the data obtained from these are stored in the Environmental Protection Agency data base, STORET. Water quality parameters selected were nitrogen, phosphorus, dissolved oxygen, biological oxygen demand and turbidity, i.e. because of their relationships to aquatic macrophyte growth and the availability of consistent records for the study period.

In order to create a computer data base that could be utilized with the various data sets to assess water quality and the distribution of aquatic macrophytes, all data sets were converted to a raster format compatible with the cell based GIS software package, MAP, available from Spatial Information Systems. This package is designed for use on an IBM PC/AT or compatible computer and contains all the necessary analytical functions required for lake management applications. However, in order to improve the GIS functionality, the Desktop Digitizing Package (DDP) was added. The MAP/DDP software combination provided an inexpensive, easy to use, GIS capability suitable for most resource management tasks. All maps were manually digitized and the data was converted to MAP using CAPTURE and

RASTER routines. A grid cell (pixel) size for data storage of 25 m x 25 m was established - this scale might appear large but in terms of speed of work and resolution accuracy it was the most satisfactory compromise.

Table 7.9 Aerial Photo Characteristics of Aquatic Macrophytes in Lake Marion

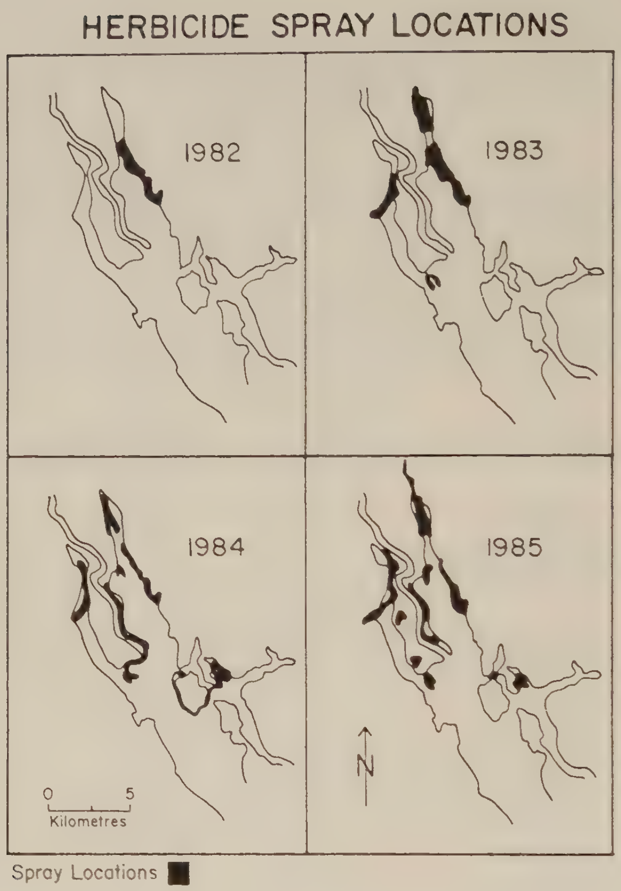
Aquatic Macrophyte	Color	Height	Texture
EMERGENT SPECIES			
Dollar bonnet	white to pale pink	floating	fine
Lotus	light to bright pink	floating to medium	fine to medium
Primrose	purple to pink	low to medium	medium
Water lily	white to pale pink	floating to low	fine
Unidentified Emergent	white to bright pink	floating to medium	fine to medium
SUBMERGENT SPECIES			
	Dark blue to black	subsurface to floating	fine
FREE FLOATING SPECIES			
Duckweed	white	floating	fine
MIXED SPECIES			
Emergents Dominant	pink to dark pink	floating to medium	medium
Submergents Dominant	blue to black	subsurface to low	fine to medium
Free Floating Dominant	white to pale pink	floating to low	fine to medium

Results/Conclusions

Overall, the total area of aquatic macrophytes remained at about 1 800 ha between 1972 and 1984, although the ratio of emergents to submergents changed significantly - emergents steadily increased, whereas submergents decreased. A decrease of about 140 ha in the area of submergents resulted from the 1985 annual herbicide application; however, emergent and free-floating macrophytes increased by 95 ha, yielding a net loss of only 45 ha. By overlaying the herbicide dispersal map with the map showing the changes in macrophyte distribution between June and September, an integrated map product is produced that reveals a substantial decrease in submergents outwards for about 200 meters from the original spray area.

Preliminary results of a spatial comparison of macrophyte distributions and water quality indicate that between 1972 and 1985 the distributions of nitrogen, DO and BOD were not related to the vegetal growth trends. However, there is some indication that the growth in emergent macrophytes after 1983 was related to sharp increases in the phosphorus levels recorded between 1980 and 1983.

Figure 7.29 Herbicide Spray Locations in Upper Lake Marion, 1982-85


HERBICIDE SPRAY LOCATIONS
1982
1983
1984
1985
0
5
Kilometres
N
Spray Locations ■

Discussion/Recommendations

The study showed various analytical methods that could be employed to monitor some typical physical/biological relationships which might occur in any large water body. The procedures used could be extended to other types of resource inventories and could be conducted with a suitably equipped IBM PC/AT or compatible machine and inexpensive GIS software designed to work with data bases in raster format.

CHAPTER 8 - CONCLUSIONS

In "stating our case" as to the relevance of both RS and GIS in making a contribution to the future success of both aquaculture and inland fisheries, it has become clear that, for a number of reasons, a brief conclusion is in order.

Firstly, the two subject areas (RS and GIS) have tended to be treated separately - we need to make it clear that the two areas have a degree of "mutuality". Secondly, we are very conscious that certain barriers remain to an easy progression for the whole field of automated location analysis, and these are very worthy of a reminder. Thirdly, we feel it essential that a reinforcement is made of some of the more important practical systems adoption considerations. This is largely a result of the complexity of the subject matter and because of the rapid changes which are now taking place in both GIS and RS. This leads us to belive that a number of recommendations are in order.

When RS was first envisaged and activated in the 1960s and early 70s, there was a sense in which the object of the science was simply to obtain a "picture of a place". The picture (image) might have a number of uses which were primarily concerned with identification, spatial proportion, aerial estimation, etc., and the number of usable images was limited by technical processing limitations, resolution problems and cloud cover. So the frontiers of RS had distinct limitations. The proliferation of GIS in the late 1970s, with its rapid ability to make use of RS images in a number of ways, and indeed its frequest fundamental need for imagery as a primary data source, plus the ability of RS to capture a wider range of images through the use of more varied sensors and an increased effectiveness in data extraction, has enabled the two disciplines to help each other and to broaden their raisen d'être. This mutual adoption was a highly necessary step if RS was to have an assured future. From the perspective of aquaculture and inland fisheries it is especially significant, since over the next decade we will be seeking to optimize fish production in a variety of locations, many of which are certain to be in areas which are remote or poorly mapped and for which the "real time" digitized data emanating from RS sensors will prove absolutely invaluable.

Though much of what we have previously explained on the more theoretical aspects of RS may have been useful with regard to process explanation and understanding, when the use of RS as a means of data acquisition is adopted then it is the acquisition procedures themselves which are of paramount importance. Specter (1989) has set out an excellent summary on the barriers to imagery acquisition, as faced by many developing countries, and he foresees considerable investments being made in money and expertise during the next decade with a view to improving the RS technology and data transfer systems to those areas. Significant reductions in the price of products would seem an essential pre-requisite for increased RS uptake, as would assistance in training and education in technology use.

With the advent of more "players" on the RS scene, then it is likely that increased competition will be beneficial in not only reducing prices but also in increasing the range and quality of images available. We recommend that potential RS users make every effort to "shop around" for suitable imagery. Cordell and Nolte (1988b) were able to verify that a huge quantity of RS data was available, i.e. from different satellites, for different times, at different resolutions and from various sources. With this data proliferation then, if sufficient or regular quantities of RS imagery are required, we suspect that tendering or contracts could be entered into so as to achieve cost advantages. And in searching for suitable imagery sources we would make a reminder that aircraft photographic sources could prove invaluable, especially in situations of micro-scale location analysis.

With regard to GIS we feel it important to re-inforce a number of separate practical issues and to make specific recommendations

i) *Uses for the GIS.* In section 6.7.1 we made it clear that considerable planning should be undertaken regarding the desired applications for the GIS. Relative to aquaculture and inland fisheries this will mostly cover considerations of optimizing production locations, a task which will also encompass an analysis of production function variability. However, with imagination the utility of a GIS can be greatly enhanced. Examples of added investigations include:

a) Planning for water body resource zonation.
b) Recording of existing ecological variability.
c) Zonation mapping of aquatic species.
d) Answering "what if" questions, i.e. if planned changes affecting water bodies were to be implemented.
e) Temporal/spatial studies of meat/fish consumption or production changes.
f) The likely effectiveness of various marketing strategies.
g) The impact on production of temporal or spatial changes in input sources.
h) The impact of communication or infrastructural changes on production location.
i) The environmental impact of intensifying fish production.
j) Spatial inconsistencies in the demand/supply balance.
k) The recognition of core areas where the diffusion of fisheries innovation might spread from.

As well as the potential uses identified it is important not to forget that changes in the scale at which GIS investigations are applied will allow for a variety of different potential uses.

ii) *How best could the GIS be implemented.* Very great care needs to be given to the "levels" of implementation of the system. We would strongly recommend that a "top down" approach is used, i.e. rather that individual small departments setting up their own systems. With a "top down" approach there will be expertise and hardware available, sufficient resources for experimentation, the likelihood of some data archives and the backing of the management who are likely to be responsible for further GIS investments. Also, future developments can expand in such a way that data structure, hardware, software, etc. is compatible, standardized and thus available for integration, and rapid expansion can occur, if necessary, both within and between departments.

iii) *The inter-disciplinary nature of the GIS team.* We have spoken at length on the complex nature of all our subject matter, and we have noted (in section 6.7.6) the recommendations for having personnel from several disciplines in any team setting up a GIS. Here we would stress that, for the successful functioning of a GIS at a significant scale, not only is it essential that a variety of experts in obvious fields are assembled, but that these experts are able to have clear access to both the staff who make the GIS function (digitizers, programmers, etc.) and to a variety of other personnel such as data archivists, representatives of mapping houses, software and hardware companies and perhaps specialist consultants. Though these personnel might be expensive "luxuries" for the more remote fisheries offices, their accessibility should be well documented.

iv) *Knowledge of data sources.* We have shown that a major problem for GIS in general is the accessibility to, and knowledge of, data sources. It seems that the barriers to instigating centralized and accessible digital data archives are almost insurmountable, i.e. regardless of country or theme. Because data acquisition is so expensive it behoves the GIS planner to investigate thoroughly requisite sources. We recommend that at least one member of any GIS team should be given specific responsibility for data acquisition. This member needs to be familiar with likely digital sources, with data distribution networks and with mapping and tabular sources both in his own country and preferably abroad.

v) *The thoroughness of data capture and structure.* The output from any GIS can only be a function of the data which has been input to the system, and it follows that weaknesses in the data will progressively replicate themselves in an exponential way with increasing use of the data. We strongly recommend that from the outset of GIS planning, considerable attention is given to the personnel and procedures necessary for ensuring that any data used is thoroughly reliable. Systems will need to be worked out to optimize the verification, correction and/or updating of data. Data accessing, digitizing and other capture procedures should be carefully considered and monitored, and thought must be given to the structuring of the data so as to ensure its efficient storage, integration potential as well as its ease of management.

vi) *Keeping abreast of developments.* The reader cannot fail to have grasped that developments within the total sphere of GIS are taking place extremely rapidly. This pace of change will be manifest along three parallel continuums:

a) What it is technically possible for a GIS to accomplish.
b) How a GIS can physically function.
c) The cost of implementing and using a GIS.

We must therefore emphasize the importance of keeping abreast of these developments. This may mean a commitment to a number of strategies including attending relevant courses and/or conferences, subscriptions to academic or trade journals, membership of professional associations, the acquisition of promotional literature and of being aware of what other companies, organizations or associations are doing.

To conclude this study we quote from Tomlinson (1989 - p.291-292) - "As space becomes more crowded, place becomes increasingly important. The public is expected to demand greater government involvement in such complex problems, thereby increasing both the responsibilities of government and the numbers of people addressing the issues. There will be more players with complex, interlocking spatial problems. There will be an increased demand for GIS capabilities at all levels of government, reflecting local, regional, national, multinational; and global concerns..." The application of RS and GIS to aquaculture and inland fisheries can be our contribution to meeting these needs.

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